CHAPTER 11 - SELECTION TECHNIQUES

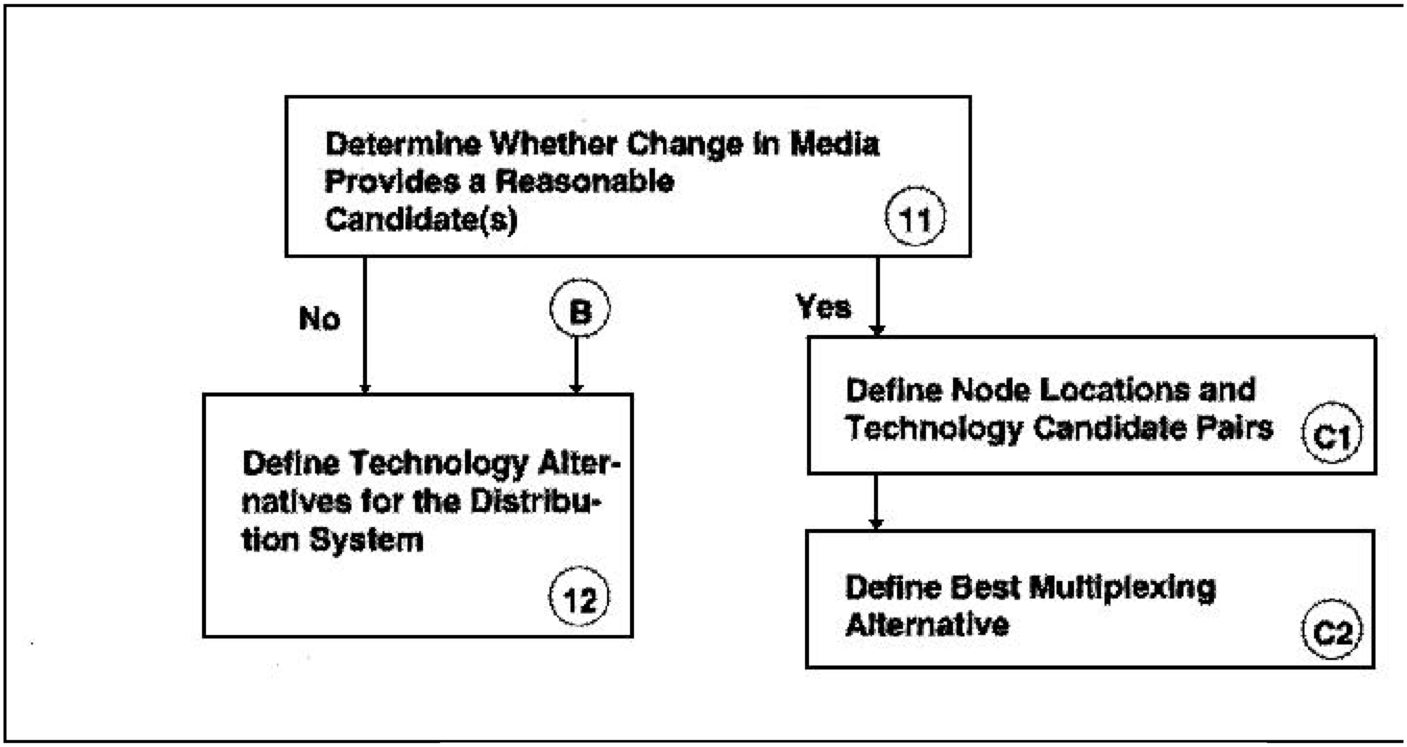

Figure 11-1 Decision Flow Chart

Introduction

Prior sections of the handbook have described communications requirements, architectures and alternative technologies. To provide a basis for selecting technologies for an application, this chapter defines generic communications links for the architectures of Chapter 5. The chapter then identifies the relationship between these generic links and the technologies which can service these links. It then describes a methodology which applies these relationships to traffic control system requirements and design constraints. Several examples illustrate application of the methodology.

Need

The transportation professional needs a methodology for selecting compatible marriages between technology and architecture. Often, several technologies can serve in a traffic control system depending on the function performed by each communications link. The designer needs a general guide and procedure to assist in selecting the appropriate communications architecture and technology for a cost effective communications system.

Purpose

This chapter assists the system designer in the selection of appropriate communication architectures and technologies. It presents procedures as a complete series of steps, but the designer can use a smaller subset in any given case. The process results in a preliminary communications system design. A detailed design will normally follow the technology selection provided by the methodology described in this chapter.

Organization

Table 11-1 summarizes the organization of this chapter.

Section Title	Purpose	Topics
Generic Links	Methodology for generalizing communication architectures	• Defines data link types
Technology/Generic Link Relationships	Summarizes technology characteristics and relates them to architectures	• Defines technology properties, relates technologies to generic links, identifies suitable technologies
Approaches and Procedures	Describes methodology to select data communication architectures and technologies	• Series of steps and flow charts outlining decision process
Examples	Provides several examples which illustrate the selection process	• CBD traffic signal system without video • Closed loop system for suburban arterial • Freeway surveillance and control system

Table 11-1 Organization of Chapter 11

Generic Links

Figure 11-2 depicts some common traffic system architectures with their associated communication links. These have been categorized into generic data communications links to represent most traffic systems.

Control Center to Field Controller (CCFC)

This link type interconnects a control center and field controller where no computation or change in data rate occurs.

Control Center to Field Master (CCFM)

The field master in the figure often controls a closed loop system. More generally it represents a field computer which does not directly control the intersection or freeway site but rather processes data and adds information and/or control content.

Field Master to Field Controller (FMFC)

This generally represents a low data rate (e.g., 1200 baud) link.

Control Center to Field Multiplexer (CCFX)

The field multiplexer site provides higher data rates to the control center link than to the field controller. While the data rates differ, the multiplexer performs no processing related to traffic system functional requirements.

Control Center to Media Converter (CCMC)

Normally, this represents a high bandwidth link providing a high data rate path to the field.

Communication Hub to Communication Hub (CHCH)

This represents a high data rate backbone link.

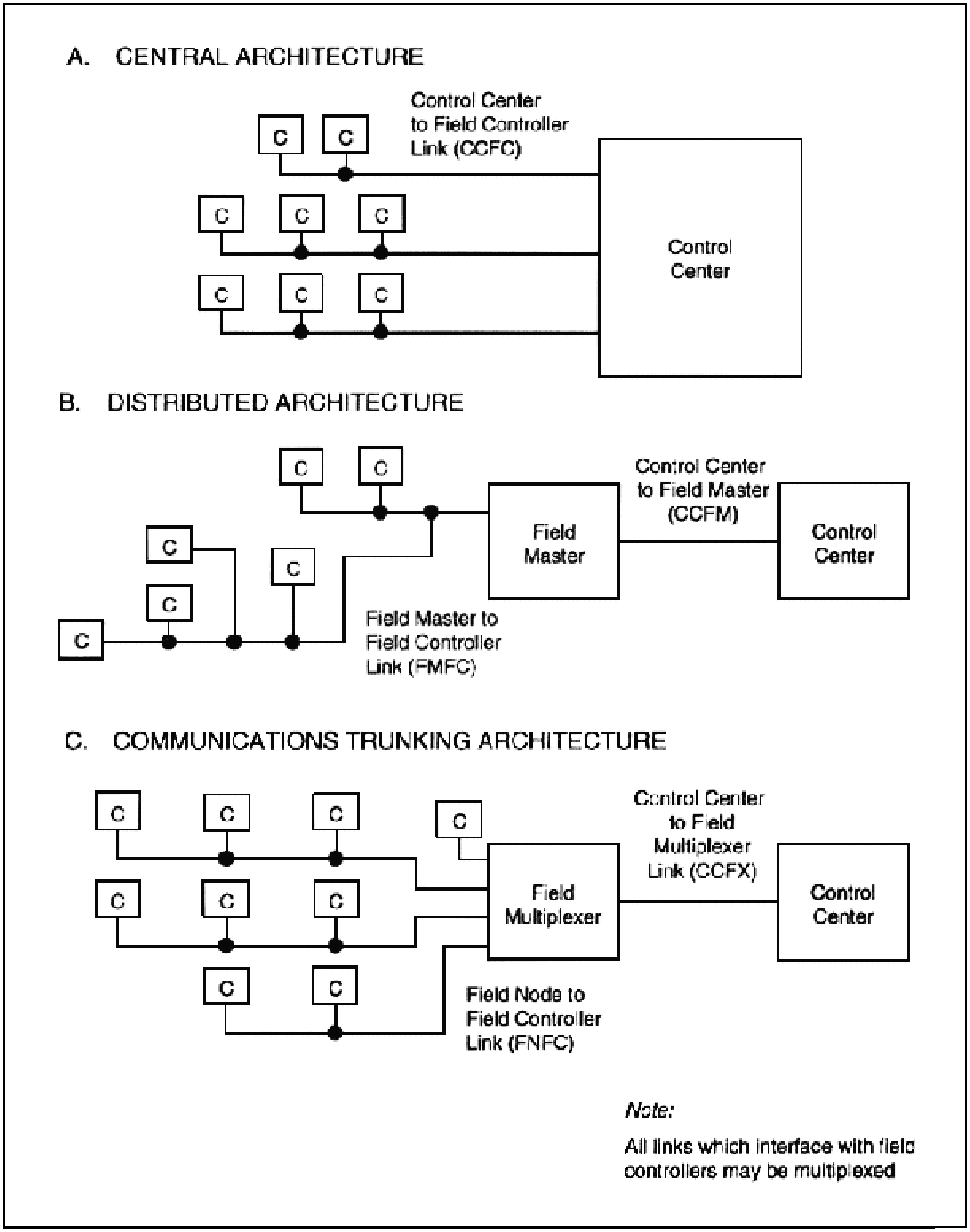

Figure 11-2 Communication Links of Several Communication System Architectures - #1

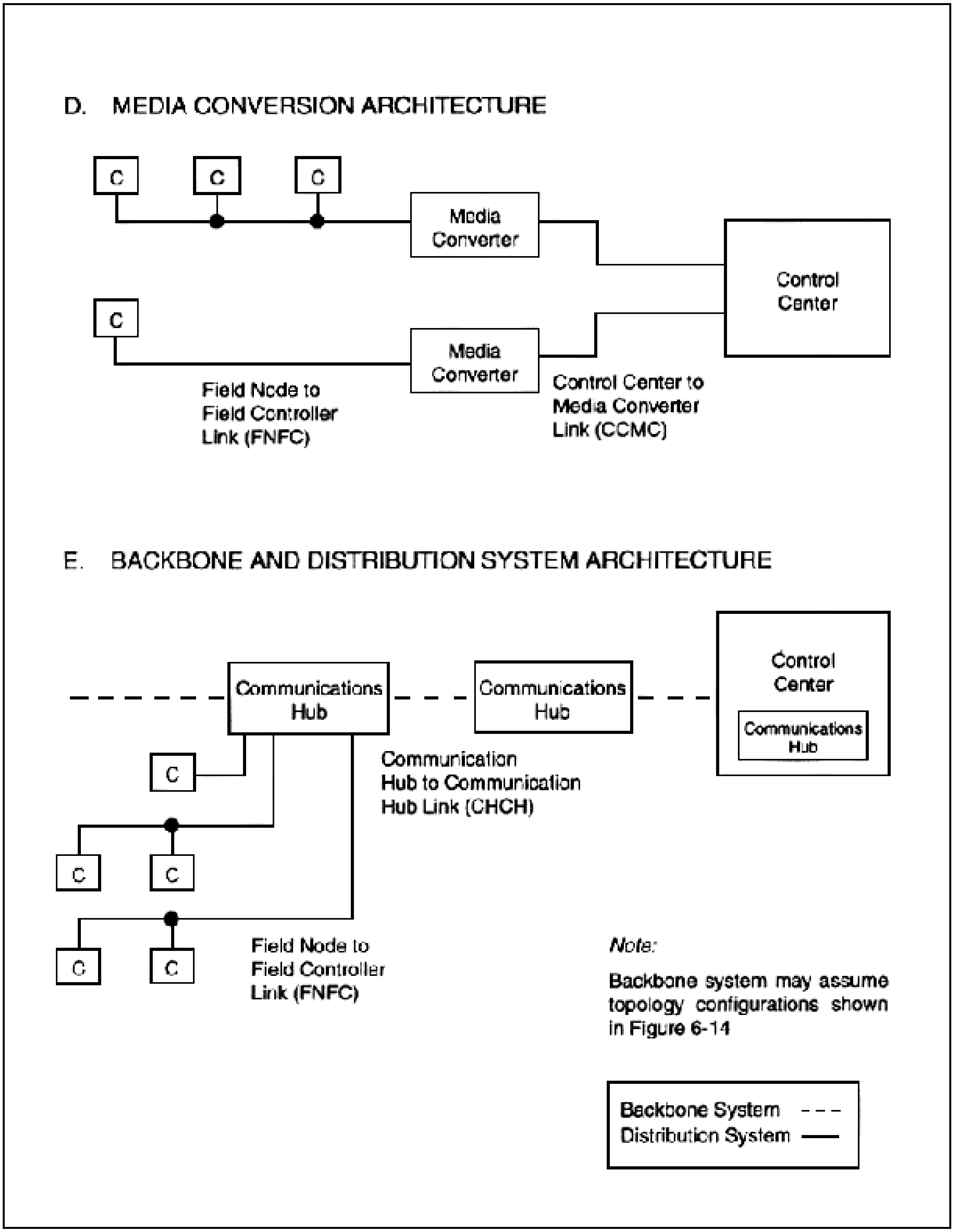

Figure 11-2 Communication Links of Several Communication System Architectures - #2

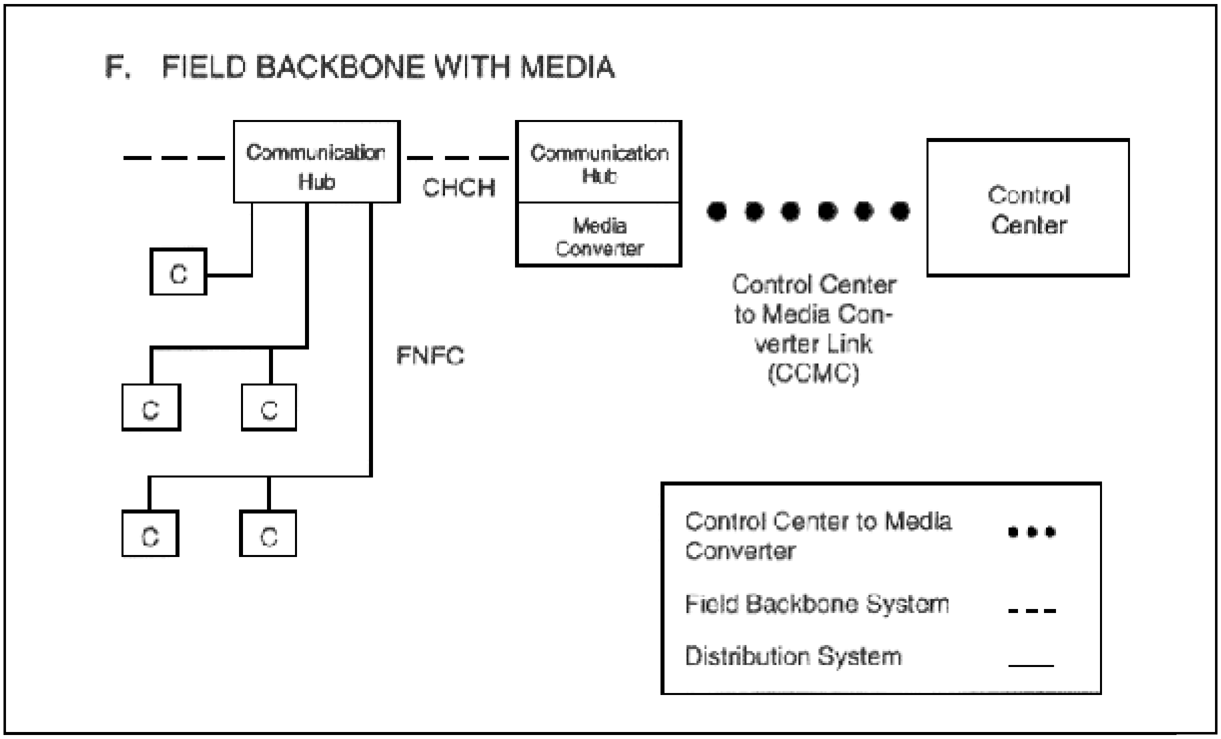

Figure 11-2 Communication Links of Several Communication System Architectures - #3

Field Node to Field Controller (FNFC)

The field controller connects to a field node for either of the following purposes:

- To provide a higher order of multiplexing by means of trunking or backbone systems between the control center and field node (CCFX, CHCH) by means of a field multiplexer.
- To use a medium more suitable for communication to the control center while retaining essentially the same communication channel capacity (CCMC). The field node in this case essentially consists of back-to-back modems to service each medium.

The remainder of this chapter uses the generic communication link concept shown in Figure 11-2.

Technology/Generic Link Relationships

Table 11-2 summarizes the properties for the most popular data communication technologies.

Table 11-3 relates the technologies in Table 11-2 to the types of generic communication links for which they are most commonly used. Tables 11-3a and 11-3b show the relationships for data and video signals respectively. Note that link types CCFM and FMFC do not apply to video signals and are not included on the chart. Note also that certain technologies can only carry video when used in connection with digital encoding (codec) as described in Chapter 4. In some cases two technologies may be used in series for one communication link. For example, the right hand portion of Figure 5-5 shows the control center to field controller link (CCFC link) serviced partly by a digital channel service and partly by spread spectrum radio.

Features	Twisted Wire Pair Channels	Leased Voice Grade Channels	Switched Voice Grade Channels	Fiber Optics Channels	CATV (Community Antenna Television) Channels
1. Media	Copper wire	May vary along length but usually copper wire pair at user interface points	May vary along length but usually copper wire pair at user interface points	Glass or plastic fibers	Coaxial Cable
2. Principal Multiplexing/ Modulation Technique Used	Time Division Multiplex (FSK)	Time Division Multiplex (FSK)	Time Division Multiplex (FSK)	Time Division Multiplex	FDM for channels. TDM for data on a channel
3. Carrier Frequency Band	300 - 3,000 Hz	300 - 3,000 Hz	300 - 3,000 Hz	850 - 1,550 nanometers	5 - 350 MHz
4. Bandwidth/Channel Bandwidth	Will exceed 2.7 kHz for most systems	2.7 kHz	2.7 kHz	Various	6 MHz/channel. Channels may be further subdivided for data transmission
5. Data Rates per Channel	1,200 - 3,100 bps/ second. Higher rates possible with different modulation technique	1,200 bps or higher	1,200 bps or higher	Up to 2.4 GBPS	Up to 7.5 MBPS based on channel subdivision
6. Transmission Range or Repeater Spacing	9 to 15 miles	Service level provided by communications lessor to a standard.	Service level provided by communications lessor to a standard.	Rarely a limitation when drop/insert units used at communication hubs or drop points	N/A
7. Government Regulation of Channel or Service	None	Tariffs filed with State	Tariffs filed with State	None	None
8. Types of Information Supported	Data, voice, slow scan TV	Data, voice, slow scan TV	Data, voice, slow scan TV	Data, voice, analog TV, Codec	Data, voice, analog TV, Codec
9. Owned or Leased	Owned	Leased	Dial up lines	Owned	Leased
10. Constraints on Use	—	Proximity of telephone service to field controllers	Compatibility with intermittent operation. Proximity to controller	—	Proximity of CATV cable to field controller

Table 11-2 Summary of Properties of Communication Technologies - #1

Features	Leased Digital Channel Services	Area Radio Networks (Owned)	Terrestrial Microwave	Spread Spectrum Radio
1. Media	Various	Atmosphere	Atmosphere	Atmosphere
2. Principal Multiplexing/ Modulation Technique Used	Time Division Multiplex, modulation technique varies	Time Division Multiplex, modulation technique varies	Time Division Multiplex, modulation technique varies	Various modulation techniques Time Division Multiplex Code Division Multiplex
3. Carrier Frequency Band	Baseband and various carrier bands	151 - 174 MHz 405 - 430 MHz 450 - 470 MHz 928 - 960 MHz	928 MHz to 40 GHz	902 - 928 MHz
4. Bandwidth/Channel Bandwidth	Various	25 KHz channels	Varies	Varies
5. Data Rates per Channel	Ranges from 2.4 KBPS to upwards	9.6 KBPS	Up to 7.5 MBPS depending on channel allocation	200 KBPS (typical)
6. Transmission Range or Repeater Spacing	N/A	Several miles	Range varies and may extend to several miles depending on frequency and other variables	0.5 miles to several miles
7. Government Regulation of Channel or Service	Tariffs filed with State	FCC licensing of channels for each network	FCC licensing of channels except for channels in 31 GHz band for each installation	No license in the 902-928 MHz band for the network
8. Types of Information Supported	Data, voice, Codec	Data	Data, voice, analog TV, Codec	Data, Codec
9. Owned or Leased	Leased	Owned	Owned	Owned
10. Constraints on Use	—	Channel availability, line of sight in 900 MHz band, multipath sensitivity, geometrics	Channel availability, line of sight availability, multipath sensitivity, geometrics, weather	Line of sight, geometrics, protocol compatibility

Table 11-2 Summary of Properties of Communication Technologies - #2

Comunication Technology	Generic Communication Link						
	CCFC	CCFM	FMFC	CCFX*	FNFC	CCMC	CHCH**
1. Twisted wire pair voice grade channels	✓	✓	✓	✓	✓	✓	
2. Leased voice grade channels	✓	✓	✓			✓	
3. Switched voice grade channels		✓					
4. Fiber optics channels	✓	✓	✓	✓	✓	✓	✓
5. CATV channels	✓					✓	
6. Leased digital channels	✓			✓		✓	
7. Area Radio Networks (owned)	✓	✓	✓		✓	✓	
8. Terrestrial Microwave	✓	✓	✓	✓	✓	✓	✓
9. Spread spectrum radio	✓		✓		✓		

Table 11-3a Relationship of Communication Technology to Generic Communication Link for Data Transmission

Comunication Technology	Generic Communication Link				
	CCFC	CCFX*	FNFC	CCMC	CHCH**
1. Twisted wire pair voice grade channels					
2. Leased voice grade channels					
3. Switched voice grade channels					
4. Fiber optics channels	✓	✓	✓	✓	✓
5. CATV channels	✓	✓	✓	✓	✓
6. Leased digital channels (Codec tecnology)	✓	✓	✓	✓	
7. Area Radio Networks					
8. Terrestrial Microwave	✓	✓	✓	✓	✓
9. Spread spectrum radio (Codec technology)	✓		✓		

CCFC = Control Center to Field Controller		CCMC = Control Center to Media Converter	
CCFM = Control Center to Field Master		CHCH = Communication Hub to Communication Hub	
FMFC = Field Master to Field Controller		FNFC = Field Node to Field Controller	
CCFX = Control Center to Field Multiplexer			

Table 11-3b Relation of Communication Technology to Generic Communication Link for Video Transmission

Table 11-3 serves as a preliminary screening aid to identify the most suitable technologies for data link types. The designer can use this aid in connection with the selection process described in this chapter.

Table 11-3 describes the technologies currently considered the most suitable for data and video transmission for each generic link type. The rapid growth in communication technologies and communication services will undoubtedly provide additional future candidates. If these new technologies become additional rows in Table 11-3, the designer can use the methodologies described in this chapter.

Approaches and Procedures

The series of steps presented here leads to a preliminary communications system design. Figure 11-3 provides a flow diagram of the steps described, but special situations will arise which require variations in the procedure. In these cases, the designer should modify the steps as required to match site-specific conditions.

- **Step 1:** Describe System Architecture

  The communication system represents only a portion of the entire system design. Overall control objectives, functional requirements and institutional factors play a role in determining the overall system architecture which becomes an input to the selection of communication alternatives. The designer should not modify the overall system architecture unless he or she cannot find a viable communication alternative to accommodate it. Architectural features important to the communications system design include:

- Type of system and distribution of computation, e.g., closed loop, UTCS type system, distributed computation in field (where, how).
- Type of controller, e.g., NEMA, 170, etc.
- Key functions and number of separate devices at each field controller which require communication.
- Location of field controllers and traffic control center.

· **Step 2:** Identify Candidate Communication Architectures

Identify candidate communication architectures which potentially satisfy system requirements. For example, a UTCS type system might feature communication architectures A, C and D in Figure 11-2 Identify additional suitable candidate architectures not shown in the figure.

· **Step 3:** Identify Generic Link Types

The *Generic Links* section in this chapter defines the types of generic data links associated with common traffic system communication architectures (e.g., CCFC, FMFC).

Identify all generic links shown in Figure 11-2 for the candidate communication system architectures described in Step 2.

If Step 2 identified special architectures, these may result in new generic link types and these should be identified.

· **Step 4:** Identify Candidate Technologies

Table 11-3 shows the relationship between communication technologies and compatible generic link types. This table can assist in the identification of candidate technologies for generic links.

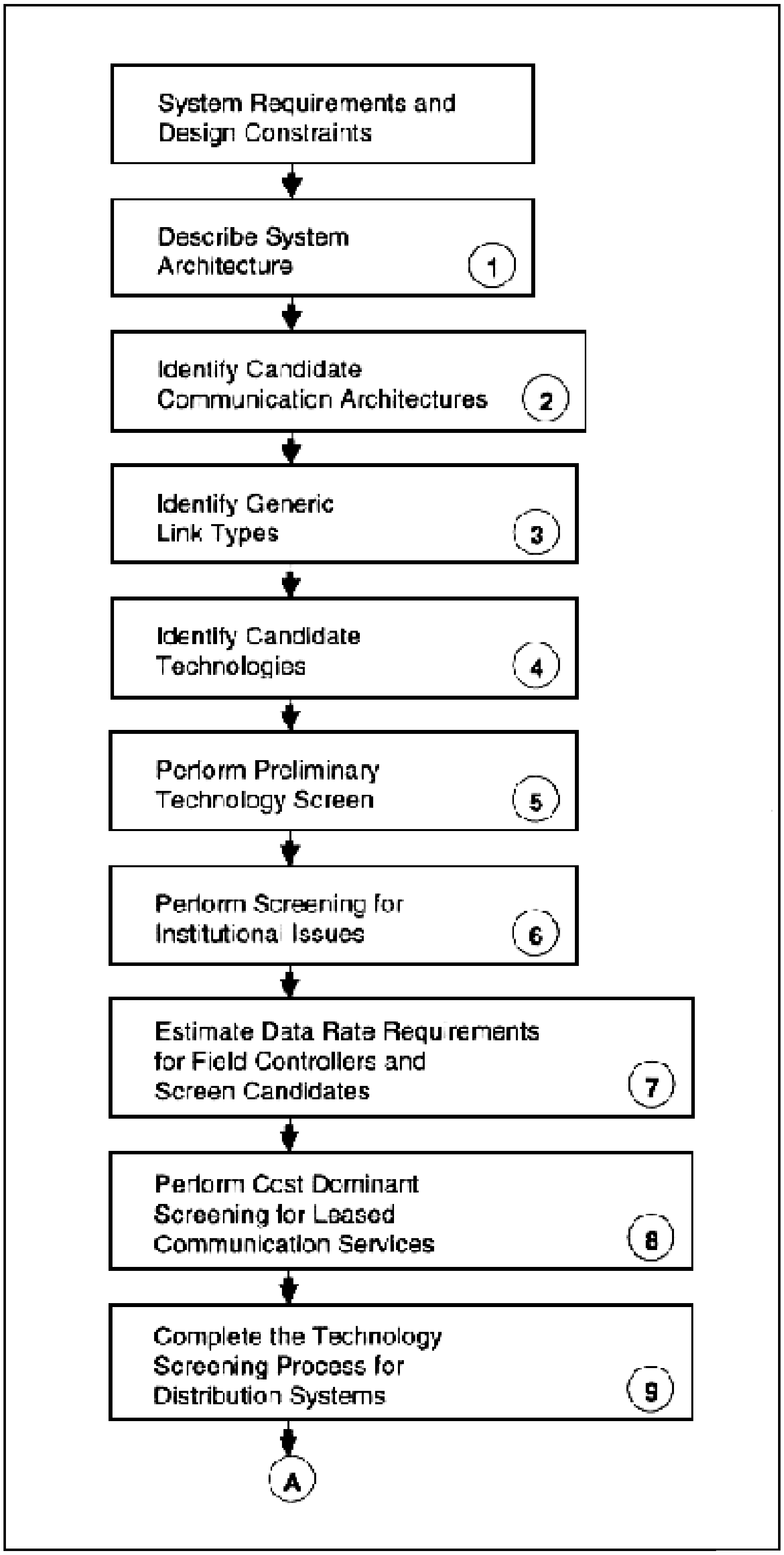

Figure 11-3 Procedure for Selecting Communications Architecture and Technology - #1

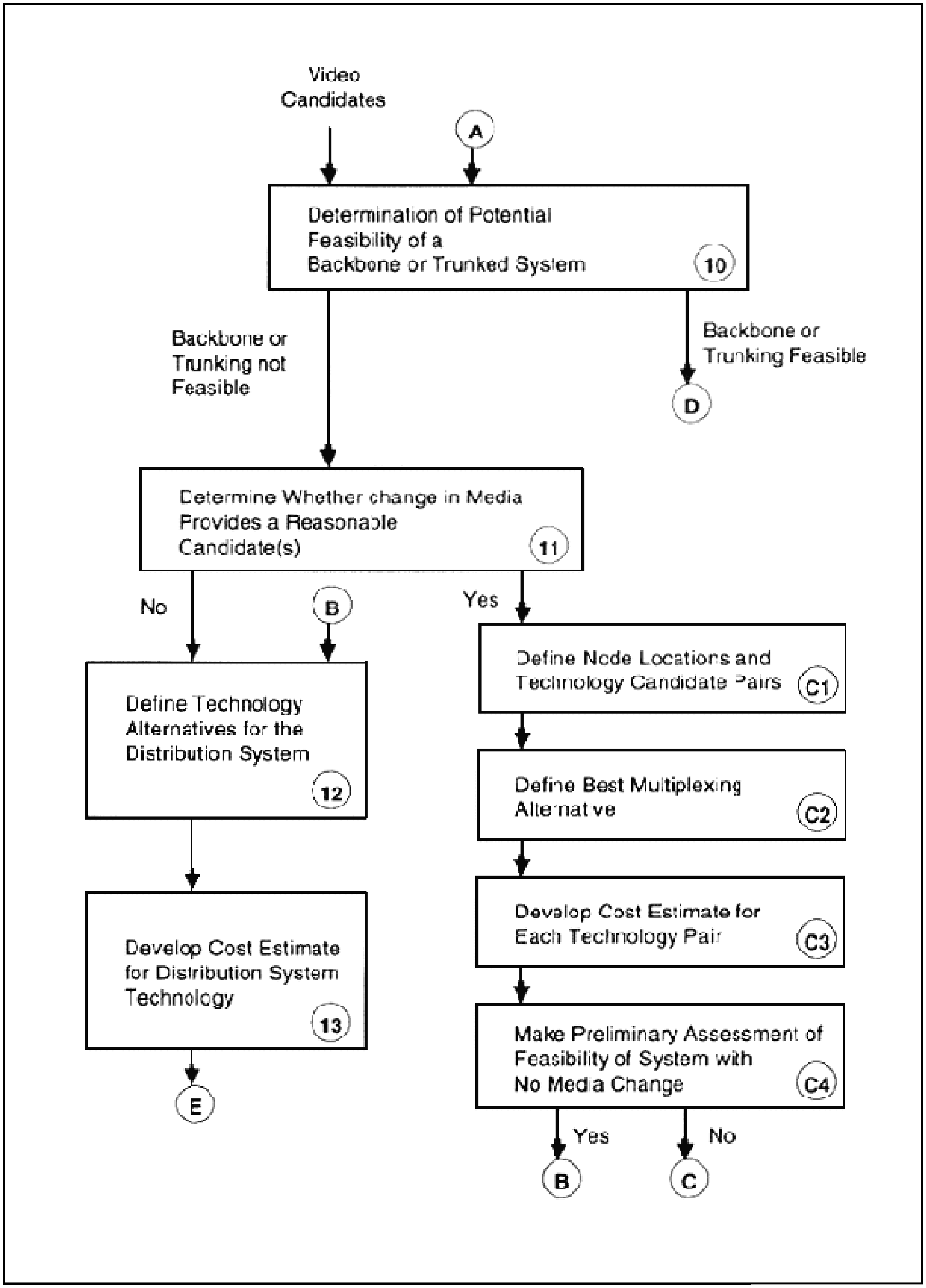

Figure 11-3 Procedure for Selecting Communications Architecture and Technology - #2

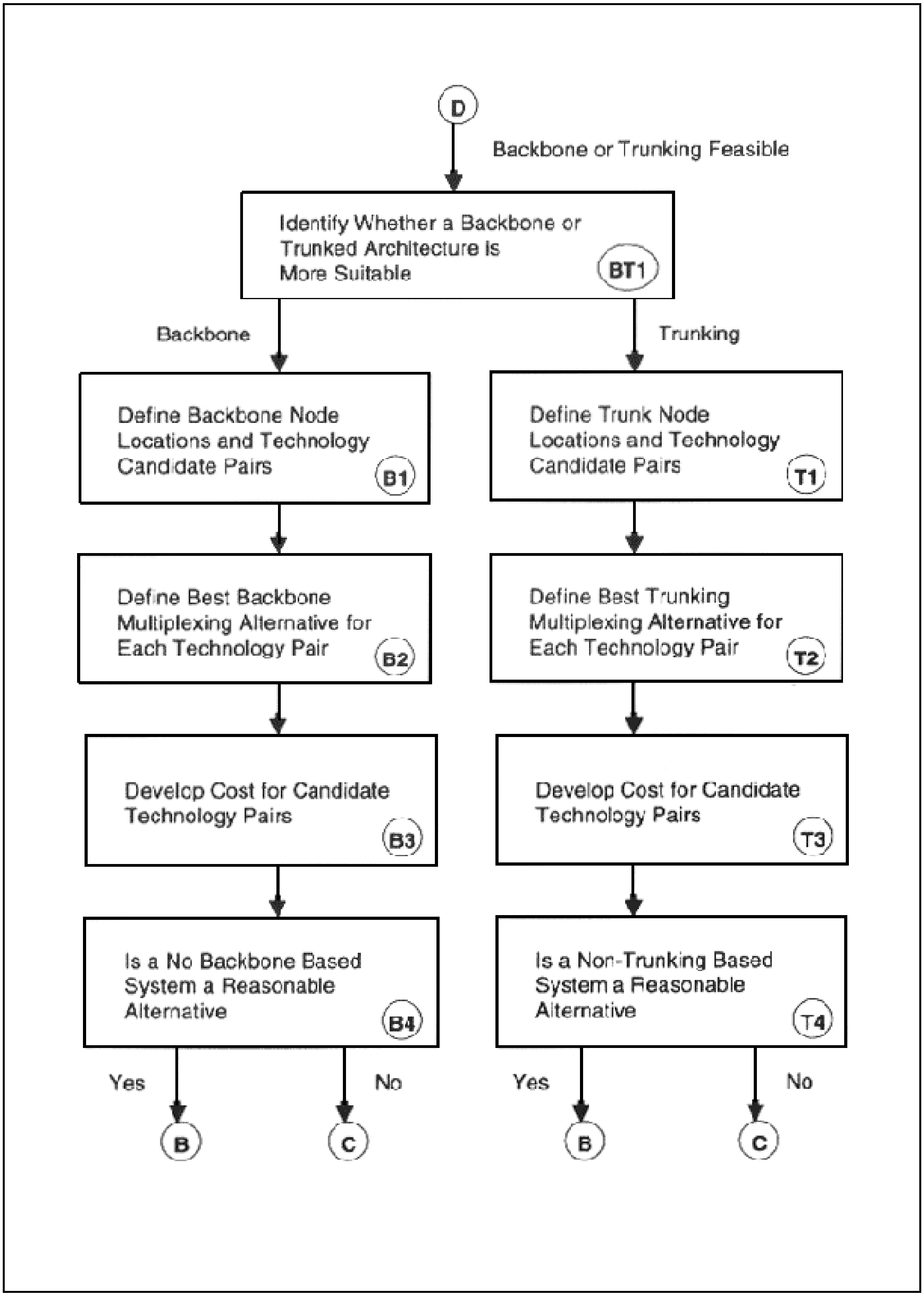

Figure 11-3 Procedure for Selecting Communications Architecture and Technology - #3

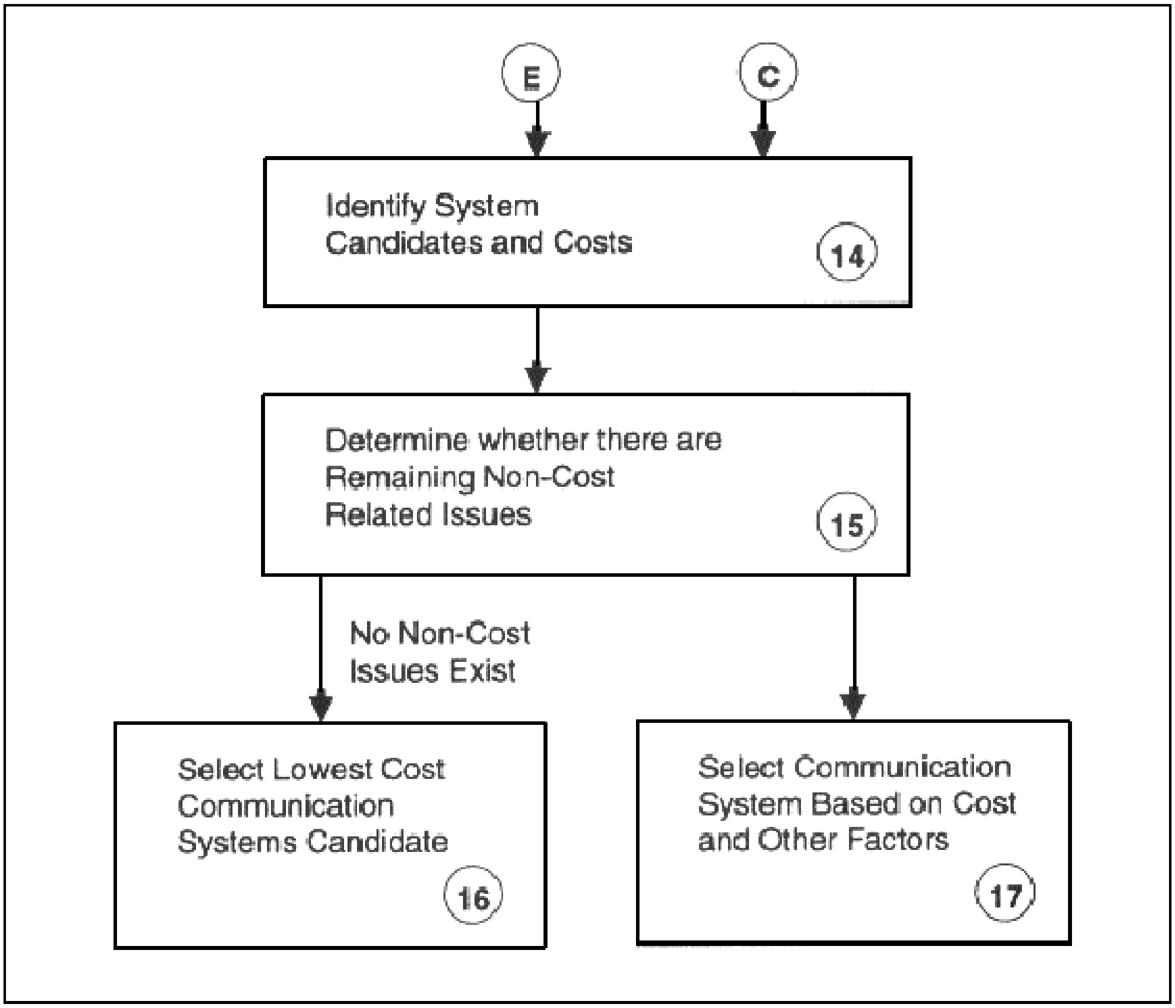

Figure 11-3 Procedure for Selecting Communications Architecture and Technology - #4

· **Step 5:** Perform Preliminary Technology Screening

The designer may eliminate certain candidates because of unavailability in the system area. For example, the local CATV installation may not:

- cover the traffic system area,
- have channels available for an area radio network, or
- have rights-of-way available for land lines.

The designer should perform the preliminary screening relatively quickly with modest effort. If he or she cannot quickly resolve some issues, retain the technology candidate for more detailed consideration and progress the analysis to Step 6.

· **Step 6:** Perform Screening for Institutional Issues

Institutional issues in selecting a communication system design may place constraints on the candidate alternatives. If such issues exist, eliminate these alternatives now if not already eliminated.

Typical reasons for eliminating candidate communication technology alternatives include:

- Avoidance of certain technologies because of lack of in-house maintenance capability or the higher cost of contract maintenance. This may also lead to the selection of leased line alternatives.
- Desire to use only standard communication interfaces and protocols to facilitate maintenance and future expansion.
- Desire to avoid potentially escalating future costs associated with channel leasing.
- Desire to limit risk which may be associated with new technologies, CATV, or various radio based technologies.

· **Step 7:** Estimate Data Rate Requirements for Field Controllers and Screen Candidates

Develop an estimate of data rate requirements for the communication channel entering the field controller. Include communication overheads for flow controls and error detection (see Chapter 5). Requirements depend on both the required functions and the system architecture selected. The designer can identify the requirements via data rate ranges such as:

- Voice grade
- Up to 9.6 KBPS
- Up to 56 KBPS
- Digital hierarchy rates (Table 6-22)

Chapter 4 and Appendix B provide assistance in estimating data rate requirements.

A voice grade channel can provide the requirements for most current traffic control. Future controllers such as the Advanced Transportation Controller (69) will have the potential to control more devices and provide more extensive processing. If certain distribution system candidate technologies cannot satisfy the field controller's input requirements, eliminate these candidates at this point.

· **Step 8:** Perform Cost Dominant Screening for Leased Communication Services

Tables 6-19 and 6-21 indicate that at present a leased voice grade channel costs much less than a digital channel. For example in New Jersey, a voice grade circuit served by a single central office leases for $76 per month. The following table shows comparable costs for digital channels:

Data Rate (KBPS)	Circuit Cost
2.4	$ 323.00
4.8	$ 384.60
9.6	$ 498.82

A 1200 BPS data rate on one or more voice grade channels will clearly cost less than the 2.4 KBPS and 4.8 KBPS alternatives regardless of multiplexing used. Furthermore, with the turnaround time and geometric constraints and the level of multiplexing feasible for most networks, the 9.6 KBPS data rate will not likely provide a cost effective alternative for communication distribution systems. With these factors in mind, review the controller data rate requirements and leased line service costs and eliminate those alternatives dominated by others.

· **Step 9:** Complete the Technology Screening Process for Distribution Systems

In Step 6, the designer performed a preliminary technology screening. That process eliminated candidates incompatible with the physical requirements of the traffic system site. Step 9 addresses any issues of this type not resolved in Step 6.

In Step 9 the principal task should assure, through vendor contacts or other means, that available equipment can:

- satisfy the functional requirements,
- interface with field controllers and other field equipment as necessary, and
- satisfy environmental requirements either directly or with environmentally conditioned enclosures.

· **Step 10:** Determine Potential Feasibility of a Backbone or Trunked System

This step screens and possibly eliminates backbone or trunking communication architectures for certain traffic system types. Where the system requires continuous or intensive CCTV coverage, the designer should consider backbone or trunked systems unless the system covers only a short distance.

In some cases, the technology permits the same link types for data and video combined over the same physical links (e.g., a T1 channel can carry both data and digitally coded video signals).

Certain traffic systems may not prove suitable for trunking or backbone systems. Common reasons include:

- The system proves too small or has too low a data rate to benefit from a backbone or trunk. For example, a single typical closed loop system using a 1200 bps communication channel would not serve as a candidate for trunking.
- The system is too geographically dispersed to permit the accumulation of a data stream at one or more points sufficient for trunking or multiplexing.
- The operating agency may consider available trunking technologies unsuitable because of:

• reliability,
• ease of access, or
• maintenance considerations.

Figure 11-3 shows a series of steps (10, 11, 12, C1-C4, BT1, B1-B4, T1-T4) designed to assess the feasibility of backbone, trunking and media change design alternatives, together with costs. Depending on the system design, the designer should not always perform these steps in the order shown but should still consider the issues described. These steps define a set of candidate systems at a technology level which can be costed.

If the designer does not consider backbone or trunking techniques feasible, proceed to Step 11 shown in Figure 11-3. If the techniques appear feasible, proceed to Step BT1.

· **Step 11:** Determine Whether a Change in Media (Link Combination FNFC/CCMC) Provides a Reasonable Candidate(s)

Systems which change media while preserving the same channel capacity may prove useful in certain geometric or physical situations. Examples include the following:

- The control center lies some distance from the traffic system field site (and providing owned media to this site proves economically unfeasible), but owned distribution systems at the field site may prove feasible.

- Water crossings or other barriers interrupt right-of-way.

· **Step 12:** Define Technology and Multiplexing Alternatives for the Distribution System Technology

This path treats link types (CCFC, FMFC, and FNFC) which directly interface with the field controller.

For each link type in the remaining set of candidate architectures, define the best multiplexing alternative for each remaining technology option. Consider the "no multiplexing" alternative. This proves a commonly selected alternative for distribution systems used in connection with backbone systems (Figure 11-2E).

Step 7 identified a channel data rate requirement for one technology (usually based on voice grade channels). While other technologies such as fiber optics will support such a channel, they will also support higher data rate channels. These will allow a higher level of multiplexing and reduce the number of required channels. This step therefore results in a multiplex plan for each remaining candidate technology including the number o distribution channels required.

For large backbone based systems, an estimate of distribution channels for a representative sample of communication hubs will suffice for the purpose of estimating the cost of this alternative in Step 13.

· **Step 13:** Develop Cost Estimate for Distribution System Technology Candidates

Include capital and operating costs for each technology and each distribution link type. Perform a capitalized cost analysis.

· **Step 14:** Identify System Candidates and Costs

At this point, the designer has estimated costs for all surviving technologies and link types. For each system architecture (combination of link types into configurations shown in Figure 11-2), and using the cost data from preceding steps, identify the costs for each compatible combination of technologies. This defines all system technology candidate combinations.

· **Step 15:** Determine Remaining Non-Cost Related Issues

The preceding steps have described a procedure where the design eliminated communication candidates because of one of the following reasons:

- Technical incompatibility with system requirements.
- Incompatibility with institutional requirements as established by the operating agency.
- Identification of a similar but less costly candidate.

The cost analysis of Step 13 may result in two or more low cost candidates whose costs do not substantially differ. If this occurs, look more closely at factors not completely quantified in terms of costs or benefits. Typical examples include:

- Risk of escalating future leased channel costs.
- Differences in service reliability between owned lines, leased services, and radio communications.
- Ease of maintenance.

If no such issues exist or if a great disparity exists between the least expensive alternative and the next alternative, proceed to Step 16. Otherwise, identify the issues and proceed to Step 17.

· **Step 16:** Select Lowest Cost Communication System Candidate

· **Step 17:** Select Communications System Based on Cost and Other Factors

The designer identified factors other than cost in Step 15.

Because communications represents only one component of the traffic control system, evaluation techniques such as benefit/cost and utility/cost analysis (65) may not adequately differentiate among competing communication system alternatives. The designer should use these factors, together with engineering judgment, to make a final selection.

· **Step 18:** Review and Iterate

The designer selected a communication system in Steps 16 and 17 based on the Step 1 architecture and institutional issues screening (Step 6). The input assumptions to Step 6 may result in an unnecessarily costly system or one with other undesirable features.

Thus, the designer should review the selected communication system for overall system function and cost. If not satisfactory, the designer should review and modify traffic system requirements and institutional issues, if necessary, and repeat the communications design procedure to enhance function and/or cost.

Media Change Flow Chart Path

Use this flow chart path when not considering a backbone or trunk system as a candidate. Step 11 identified a potential need for a media change in one or more communication paths from the traffic control center (Link CCMC in Figure 11-2D).

· **Step C1:** Define Node Locations and Technology Candidate Pairs

A communications architecture with a media change includes generic link types FNFC and CCMC (Figure 11-2D). Step 9 identified the useful technologies for link type FNFC. Couple these with the surviving technologies for link type CCMC resulting from Step 6 to establish a complete set of FNFC/CCMC link type technology pairs. Establish approximate locations for the media change modems.

· **Step C2:** Define Best Multiplexing Alternative

Define the best multiplexing alternative for each candidate technology pair from Step C1. Consider the no multiplex alternative. Define the data rate for the link type pair and estimate the number of channels required.

- **Step C3:** Develop Cost Estimate for Each Technology Pair

Include capital and operating costs for each technology pair. Perform a capitalized cost analysis.

- **Step C4:** Assess Preliminary Feasibility of a System with No Media Change

Combinations of certain factors (e.g., no right-of-way or inaccessibility of telephone tie points) may make impractical or impossible a complete communication path using a single medium. In other cases economic factors may dictate serial media links. When a media change is necessary, proceed to Step 14; otherwise proceed to Step 12 to complete the analysis of single media alternatives.

Backbone or Trunking Flow Chart Path

Use this flow chart path when Step 10 indicates a backbone or trunked architecture (i.e., using a higher data rate channel than the distribution system supports) may prove the best alternative.

- **Step BT1:** Identify Whether a Backbone or Trunked Architecture is More Suitable

Figure 11-2C shows a trunked architecture as characterized by a high data rate path from a field multiplexer to the control center. The multiplexer may service several distribution networks. Figure 11-2E shows a backbone system as consisting of a series of communication hubs interconnected with high data rate channels. Each hub services one or more distribution systems or single controllers. Add-drop units commonly service backbone hubs.

This step entails examination of the geometric relationship of the controllers and selection of the best alternative or combination described above. For example, surveillance locations spaced at intervals of 0.25 to 0.5 miles along a freeway (with or without control functions) may connect through a distribution system to a backbone with hubs spaced at distances in excess of one mile. These hubs generally serve as connection points for video as well as data signals (see Figure 11-4A).

If, on the other hand, a central communications point services a series of communication distribution systems, a trunking architecture may apply. Figure 11-4B shows such a configuration with data sent to a remote control center. In this case, a 56 KB leased data link serves as the trunking technology.

If selecting a backbone architecture, proceed to Step B1; with a trunking architecture proceed to Step T1.

- **Step B1 (T1):** Define Approximate Backbone (Trunk) Locations and Technology Candidate Pairs

Step 9 identified the useful technologies for link type FNFC. Couple these with the surviving technologies for link type CHCH (backbone) or CCFX (trunking) resulting from Step 6 to establish a complete set of FNFC/CHCH (backbone) or FNFC/CCFX (trunking) technology link type pairs.

Establish approximate locations or spacings for backbone hubs or trunking multiplexer nodes.

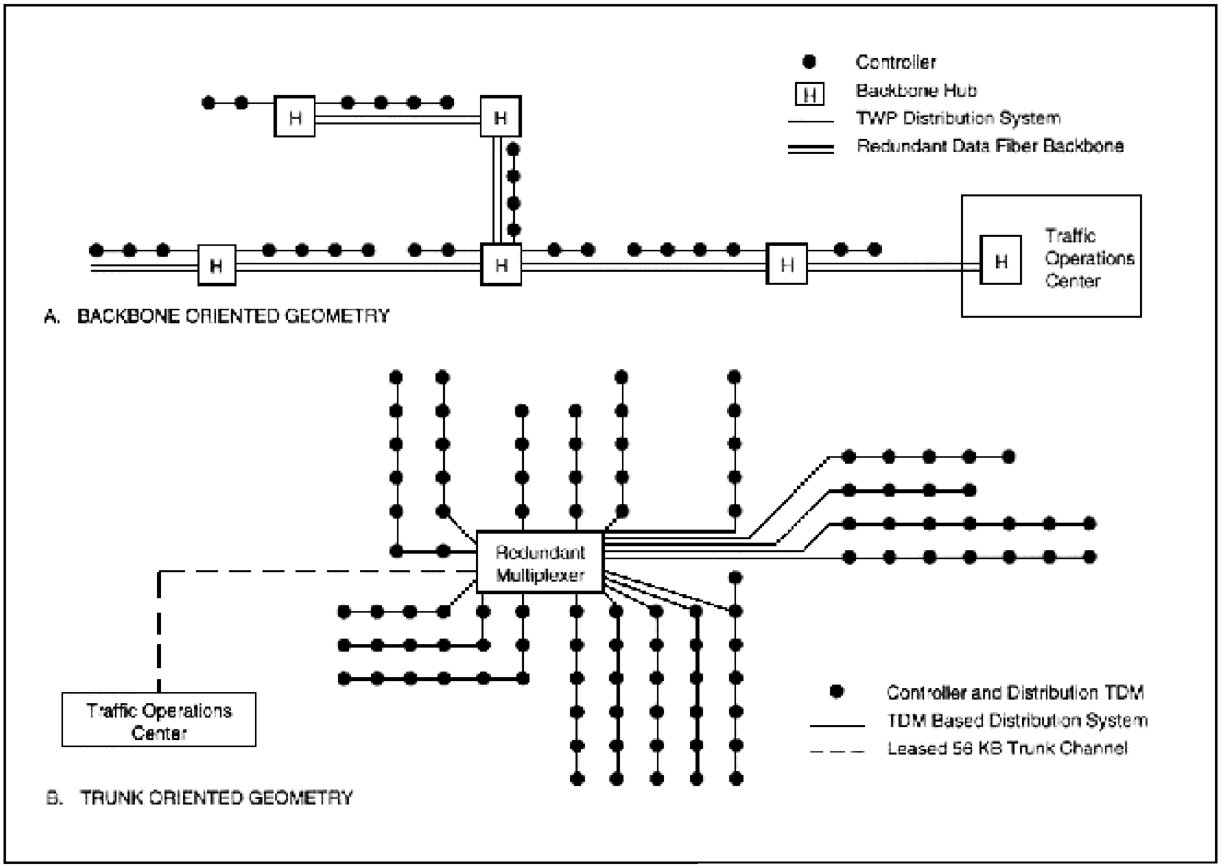

Figure 11-4 Backbone vs. Trunk Oriented Geometry

- **Step B2 (T2):** Define Best Multiplexing Alternative

  Define the best multiplexing alternative for each candidate technology pair from Step B1 (T1). Consider the "no multiplex" alternative for the distribution system. Define the data rate for the link pair and estimate the number of channels required for the distribution network and for the backbone (media).

- **Step B3 (T3):** Develop Cost Estimate for Each Technology Pair

  Include capital and operating costs for each technology pair. Perform a capitalized cost analysis.

- **Step B4 (T4):** Assess the Preliminary Feasibility of a System with no Backbone or Trunking

  Larger traffic systems with a number of distribution systems and significant data quantities likely require backbone or trunking. The requirement for TV increases the need for backbones and/or trunking. If the system will likely require backbone or trunking, proceed to Step 14. If a system without a backbone or trunking is a candidate, proceed to Step 12.

Examples

This section provides several examples of the previous steps for selection of appropriate communication system technologies.

The decision process requires that the operating agency establish certain criteria and make judgments on the acceptability of various technologies. The examples assume common criteria and judgments useful for a particular agency at a particular time, but not necessarily universally applicable.

Each of the examples emphasize and compare system design features which differ among alternatives. These differences are evaluated using sample furnish and install costs. These costs apply to one geographic location on a particular date. The designer should therefore obtain the pertinent, current local cost data as the sample costs may not prove valid.

Example 1 - Traffic Control System for CBD - No Video

Table 11-4 describes the scenario for this example; Figure 11-5 shows the location of controllers and the control center.

The following paragraphs describe the application of the procedure.

- **Step 1:** Describe Traffic System Architecture

  Figure 11-5 and Table 11-4 describe the traffic system architecture and geographic location of controllers.

- **Step 2:** Identify Candidate Communication Architectures

  The only candidate communication architecture in Figure 11-2 eliminated at this point is the distributed architecture because of inconsistency with the centralized system architecture identified in Step 1.

- **Step 3:** Identify Generic Link Types

  List the generic communication link types associated with the remaining candidate communication architectures of Figure 11-2. These link types are:

  CCFC Control Center to Field Controller
  FNFC Field Node to Field Controller
  CCFX Control Center to Field Multiplexer
  CCMC Control Center to Media Converter
  CHCH Communication Hub to Communication Hub

Location and Number of Controllers

System will initially control 196 controllers in CBD as shown in Figure 11-5. No geometric expansion of this CBD oriented system is contemplated; however, functions may be added in the future.

Traffic Control System Architecture

- Centralized traffic control system of UTCS type. Polling at one time per second.
- Use of existing NEMA TS1 and solid state pretimed controllers.

- Controllers currently on time base coordinators.
- No TV installations are currently contemplated.

Operating Agency Capability, Cuurent Resources and Institutional Issues

- Currently maintains own signals, good maintenance capability.
- Old duct system available, 20% of duct needs replacement.
- No useful franchise relationships with power company, TELCO or CATV firm.
- Only proven technology acceptable. Operating agency feels that radio has not been sufficient prior use in CBD areas.
- Use of conventional communication standards except for interface to NEMA controllers perferred.
- In the event of a single communication system equipment failure, communication will be maintained with at least 80% of the field controllers. Thus, a single communication failure should not result in the loss of communication with more than 34 controllers.

Communication Services Available

- Telco is the only communication firm currently able to provide service in most CBD areas. Use New Jersey tariffs for this example.
- CATV currently not available in CBD.

Table 11-4 Scenario for Example 1

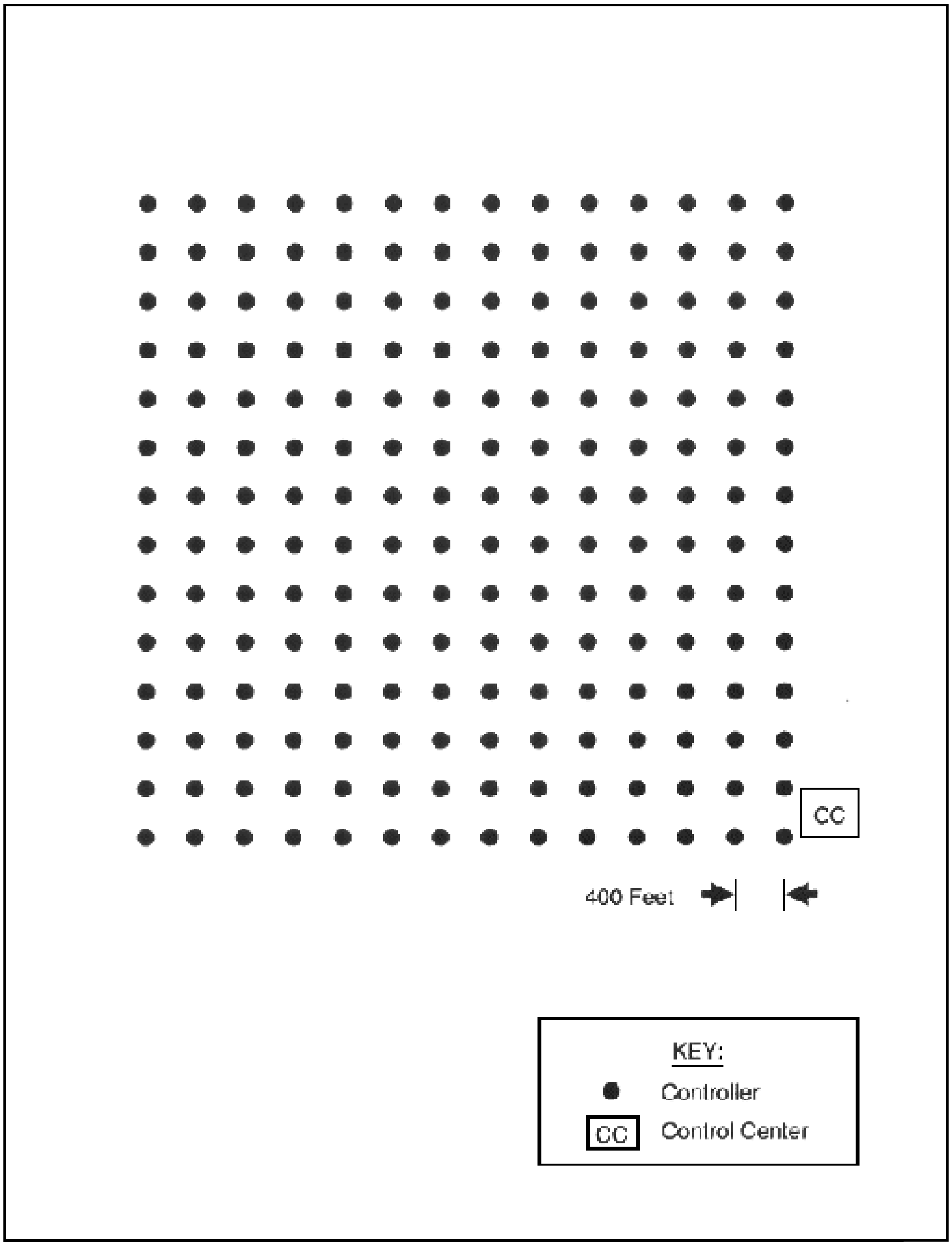

Figure 11-5 Location of Controllers and Control Center for Example 1

- **Step 4:** Identify Candidate Technologies

  From the technology/link type relationships of Table 11-3A develop the chart shown in Table 11-5 for the candidate generic link types for this system. This table forms part of a worksheet developed in subsequent steps.

- **Step 5:** Perform Preliminary Technology Screening

  Review each technology for each link type to determine whether Table 11-4 and Figure 11-5 limits or precludes its use. Since the CBD does not have CATV installed, remove from consideration. Figure 11-6 may assist in these steps, e.g., it shows termination of the CATV channel candidate for each link type. Table 11-6 provides the rationale for termination as referenced in Figure 11-6.

1. CATV not availble in area (Table 11-4).

2. Radio technologies rejected by operating agency (Table 11-4).

3. Link types CCFC and FNFC limited to 9600 BPS because of reliability considerations.

4. Link types CCFX, CCMC, CHCH limited to 9600 BPS unless redundant because of reliability considerations.

5. Use of leased voice grade channels less expensive than leased digital channels for this application.

6. RCUs available for copper pair and fiber media.

7. No cost savings possible using backbone or trunking.

8. No cost savings possible using media change.

Table 11-6 Reasons for Terminating Consideration fo Candidates (Example 1)

· **Step 6:** Perform Screening for Institutional Issues

Review each technology for institutional issues which limit its use. Table 11-4 indicates the unacceptability of radio systems. Terminate further consideration. See column 4 of Figure 11-6.

· **Step 7:** Estimate Data Rate Requirements for Field Controllers and Screen Candidates

Because the traffic control system architecture in this example replicates the architecture in the example on page 4-2, the procedures identified in Table 4-4 and in spreadsheet file SIGSHR2.WK1 described in Appendix B apply here. Running the spreadsheet for three data rates and for representative channel settling times for each data rate generates the reports shown in Figures 11-7, 11-8 and 11-9. A summary of the results follows:

Modem Data Rates (BPS)	Maximum No. Controllers/ Channel	Maximum No. Controllers/Channel with Reliability Constraint
1200	6	6
9600	28	28
56000	74	39

The number of supportable controllers becomes less than the ratio of the channel data rates because of turnaround time considerations. A single data channel should service no more than 39 controllers because of the reliability constraint. Using standard protocols, a data rate of greater than 9.6 KBPS is of marginal value for the distribution channels and consider higher data rates only for backbone or trunk channels if those channels are redundant.

TECHNOLOGY	Candidate Link Type										
1. Twisted Wire Pairs	CCFC CCFX FNFX CCMC										
2. Leased Voice Grade Channels	CCFC CCMC										
3. Switched Voice Grade Channels											
4. Fiber Optics Channels	CCFC CCFX FNFC CCMC CHCH										
5. CATV Channels	CCFC CCMC										
6. Leased Digital Channels	CCFC CCFX CCMC										
7. Area Radio Network	CCFC FNFC CCMC										
8. Terrestrial Microwave	CCFC CCFX FNFC CCMC CHCH										
9. Spread Spectrum Radio	CCFC FNFC										

Table 11-5 Candidate Link Types and Technologies for Example 1

COLUMN 1	2	3	4	5	6	7	8	9
TECHNOLOGY	STEP 4 Candidate Link Type	STEP 5 Preliminary Technology Screening	STEP 6 Institutional Issue Screening	STEP 7 Data Rate Screen	STEP 8 Perform Cost Dominant Screening for Leased Channels	STEP 9 Complete Technology Screening for Distribution System	STEP 10 Determine Potential Feasibility of Backbone or Trunking	STEP 11 Determine Whether a Change in Media Provides a Reasonable Candidate
1. Twisted Wire Pairs	CCFC			3		6		
	CCFX			4			7	
	FNFX			3		6		8
	CCMC			3				8
2. Leased Voice Grade Channels	CCFC			3		6		
	CCMC			3				8
3. Switched Voice Grade Channels								
4. Fiber Optics Channels	CCFC			3		6		
	CCFX			4			7	
	FNFC			3		6		8
	CCMC			3				8
	CHCH			4			7	
5. CATV Channels	CCFC	1						
	CCMC	1						
6. Leased Digital Channels	CCFC			3	5			
	CCFX			4	5			
	CCMC			3	5			
7. Area Radio Network	CCFC		2					
	FNFC		2					
	CCMC		2					
8. Terrestrial Microwave	CCFC		2					
	CCFX		2					
	FNFC		2					
	CCMC		2					
	CHCH		2					
9. Spread Spectrum Radio	CCFC		2					
	FNFC		2					

Figure 11-6 Candidate Analysis Summary Chart for Example 1

	SIGNAL SYSTEM - SHORT PROCESSING PERIOD (1 SEC) ASSESSMENT OF PRELIMINARY DESIGN			COMMENTS
		VALUE ENTRY		
1	MAXIMUM # SYST. DETECT. PER CONTR. - D	8		
2	MAXIMUM # LOCAL DETECT REPORTED - L	4		
3	MAXIMUM # PUSH BUTTONS REPORTED - P	2		
4	MAXIMUM # CONTROLLERS ON CHANNEL - C	6		
5	CHANNEL SETTLING TIME (SEC.) - H	0.02		FULL DUPLEX
	FLOW AND ERROR CONTROL			
6	OVERHEAD RATIO (%) - R	40		
7	DESIGN GROWTH FACTOR (%) - G	10		
8	CHANNEL DATA RATE (BITS/SEC) - B	1200		
9	COMPUTATION OF BYTES PER CONTROLLER	RELATIONSHIP	BYTES PER CONTROLLER	
10	OUTBOUND MESSAGE			
11	CONTROLLER ADDRESS	INT(1.4438LN(C) + 0.99)/8	0.375	
12	FORCE OFF		0.250	
13	HOLD, HOLD ON LINE, INTERVAL, FLASH		0.500	
14	RESET DETECTORS		0.125	
15	CALL ALL, CALL FREE, PED CALL, PHSE OMIT		0.500	
16	SPECIAL FUNCTION		0.250	
17	SPARES		0.500	
18				
19	INBOUND MESSAGE			
20	GREEN INTERVAL PRESENCE (8)		1.000	
21	CONTROLLED FROM FIELD		0.125	
22	PREEMPT, FLASH, SYST. FLSH, CONFL. MON.		0.500	
23	SPARES	0.500		
24				
25				
26	REQUIREMENTS PER DETECTOR			
27	SYSTEM DETECTOR OCCUPANCY		0.125	DATA COMPRESS.
28	SYS. DET. COUNT, END OF VEH., CHATTER		0.375	
29	LOCAL DETECTOR PRESENCE		0.125	
30	PED PUSH BUTTON PRESENCE		0.125	
31	TOTAL DETECTOR BYTES PER CONTROLLER	D*(LINE 27+LINE 28)+L*(LINE 29) + P*(LINE 30)	4.750	
32	TOTAL FUNCTIONAL BYTES/POLL/CONTROLLER	INT(SUM(LINES 11-18)+.99)+ INT(SUM(LNS 19-23)+LINE 31+.99)	10.000	
			BYTES & BITS PER CHANNEL	
33	TOTAL FUNCTIONAL BYTES/POLL/CHANNEL	(LINE 4)*(LINE 32)	60.000	
34	TOTAL FUNCTIONAL BITS/POLL/CHANNEL	8*LINE 33	480.000	
35	TOTAL BITS PER POLL WITH OVERHEAD	INT(LINE 34*(1+R/100)+.99)	672.000	
36	TOTAL BITS/POLL WITH DESIGN GROWTH & OH	INT(LINE 35*(1+G/100)+.99)	739.000	
37	TOTAL BITS/POLL/CONTROLLER INC GR & OH	(LINE 36)/C	123.167	
38	FRACTION OF CHANNEL USED	(LINE 36)/B+2*C*H	0.856	

Figure 11-7 Evaluation of 6 Controllers on 1200 BPS Channel

	SIGNAL SYSTEM - SHORT PROCESSING PERIOD (1 SEC) ASSESSMENT OF PRELIMINARY DESIGN		COMMENTS
		VALUE ENTRY	
1	MAXIMUM # SYST. DETECT. PER CONTR. - D	8	
2	MAXIMUM # LOCAL DETECT REPORTED - L	4	
3	MAXIMUM # PUSH BUTTONS REPORTED - P	2	
4	MAXIMUM # CONTROLLERS ON CHANNEL - C	28	
5	CHANNEL SETTLING TIME (SEC.) - H	0.01	FULL DUPLEX
	FLOW AND ERROR CONTROL		
6	OVERHEAD RATIO (%) - R	40	
7	DESIGN GROWTH FACTOR (%) - G	10	
8	CHANNEL DATA RATE (BITS/SEC) - B	9600	

9	COMPUTATION OF BYTES PER CONTROLLER	RELATIONSHIP	BYTES PER CONTROLLER	
10	OUTBOUND MESSAGE			
11	CONTROLLER ADDRESS	INT(1.4438LN(C) + 0.99)/8	0.625	
12	FORCE OFF		0.250	
13	HOLD, HOLD ON LINE, INTERVAL, FLASH		0.500	
14	RESET DETECTORS		0.125	
15	CALL ALL, CALL FREE, PED CALL, PHSE OMIT		0.500	
16	SPECIAL FUNCTION		0.250	
17	SPARES		0.500	
18				
19	INBOUND MESSAGE			
20	GREEN INTERVAL PRESENCE (8)		1.000	
21	CONTROLLED FROM FIELD		0.125	
22	PREEMPT, FLASH, SYST. FLSH, CONFL. MON.		0.500	
23	SPARES		0.500	
24				
25				
26	REQUIREMENTS PER DETECTOR			
27	SYSTEM DETECTOR OCCUPANCY		0.125	DATA COMPRESS.
28	SYS. DET. COUNT, END OF VEH., CHATTER		0.375	
29	LOCAL DETECTOR PRESENCE		0.125	
30	PED PUSH BUTTON PRESENCE		0.125	
31	TOTAL DETECTOR BYTES PER CONTROLLER	D*(LINE 27+LINE 28)+L*(LINE 29) + P*(LINE 30)	4.750	
32	TOTAL FUNCTIONAL BYTES/POLL/CONTROLLER	INT(SUM(LINES 11-18)+.99)+ INT(SUM(LNS 19-23)+LINE 31+.99)	10.000	
			BYTES & BITS PER CHANNEL	
33	TOTAL FUNCTIONAL BYTES/POLL/CHANNEL	(LINE 4)*(LINE 32)	280.000	
34	TOTAL FUNCTIONAL BITS/POLL/CHANNEL	8*LINE 33	2240.000	
35	TOTAL BITS PER POLL WITH OVERHEAD	INT(LINE 34*(1+R/100)+.99)	3136.000	
36	TOTAL BITS/POLL WITH DESIGN GROWTH & OH	INT(LINE 35*(1+G/100)+.99)	3449.000	
37	TOTAL BITS/POLL/CONTROLLER INC GR & OH	(LINE 36)/C	123.179	
38	FRACTION OF CHANNEL USED	(LINE 36)/B+2*C*H	0.919	

Figure 11-8 Evaluation of 28 Controllers on 9600 BPS Channel

	SIGNAL SYSTEM - SHORT PROCESSING PERIOD (1 SEC) ASSESSMENT OF PRELIMINARY DESIGN			COMMENTS
		VALUE ENTRY		
1	MAXIMUM # SYST. DETECT. PER CONTR. - D	8		
2	MAXIMUM # LOCAL DETECT REPORTED - L	4		
3	MAXIMUM # PUSH BUTTONS REPORTED - P	2		
4	MAXIMUM # CONTROLLERS ON CHANNEL - C	74		
5	CHANNEL SETTLING TIME (SEC.) - H	0.005		FULL DUPLEX
	FLOW AND ERROR CONTROL			
6	OVERHEAD RATIO (%) - R	40		
7	DESIGN GROWTH FACTOR (%) - G	10		
8	CHANNEL DATA RATE (BITS/SEC) - B	56000		
9	COMPUTATION OF BYTES PER CONTROLLER	RELATIONSHIP	BYTES PER CONTROLLER	
10	OUTBOUND MESSAGE			
11	CONTROLLER ADDRESS	INT(1.4436LN(C) + 0.99)/8	0.875	
12	FORCE OFF		0.250	
13	HOLD, HOLD ON LINE, INTERVAL, FLASH		0.500	
14	RESET DETECTORS		0.125	
15	CALL ALL, CALL FREE, PED CALL, PHSE OMIT		0.500	
16	SPECIAL FUNCTION		0.250	
17	SPARES		0.500	
18				
19	INBOUND MESSAGE			
20	GREEN INTERVAL PRESENCE (8)		1.000	
21	CONTROLLED FROM FIELD		0.125	
22	PREEMPT, FLASH, SYST. FLSH, CONFL. MON.		0.500	
23	SPARES		0.500	
24				
25				
26	REQUIREMENTS PER DETECTOR			
27	SYSTEM DETECTOR OCCUPANCY		0.125	DATA COMPRESS.
28	SYS. DET. COUNT, END OF VEH., CHATTER		0.375	
29	LOCAL DETECTOR PRESENCE		0.125	
30	PED PUSH BUTTON PRESENCE		0.125	
31	TOTAL DETECTOR BYTES PER CONTROLLER	D*(LINE 27+LINE 28)+L*(LINE 29) + P*(LINE 30)	4.750	
32	TOTAL FUNCTIONAL BYTES/POLL/CONTROLLER	INT(SUM(LINES 11-18)+.99)+ INT(SUM(LNS 19-23)+LINE 31+.99)	10.000	
			BYTES & BITS PER CHANNEL	
33	TOTAL FUNCTIONAL BYTES/POLL/CHANNEL	(LINE 4)*(LINE 32)	740.000	
34	TOTAL FUNCTIONAL BITS/POLL/CHANNEL	8*LINE 33	5920.000	
35	TOTAL BITS PER POLL WITH OVERHEAD	INT(LINE 34*(1+R/100)+.99)	8288.000	
36	TOTAL BITS/POLL WITH DESIGN GROWTH & OH	INT(LINE 35*(1+G/100)+.99)	9116.000	
37	TOTAL BITS/POLL/CONTROLLER INC GR & OH	(LINE 36)/C	123.189	
38	FRACTION OF CHANNEL USED	(LINE 36)/B+2*C*H	0.903	

Figure 11-9 Evaluation of 74 Controllers on 5600 BPS Channel

· **Step 8:** Perform Cost Dominant Screening for Leased Communication Services

Leased communication can serve for link types CCFC, CCFX and CCMC, identified in Step 3 as possible candidates.

A review of the tariff structures in Tables 6-19 and 6-21 indicates that termination of each drop point on digital channels costs much more than voice grade channels. Voice grade channels dominate the leased line selection for link type CCFC since:

- the various possible multiplex arrangements do not significantly affect the number of terminations, and
- voice grade channels appear adequate to satisfy data rate requirements.

Distribution systems in the field use link types CCFX and CCMC. If using this architecture, voice grade lines would still prove the most economical as evidenced by a comparison of monthly leased channel costs (all controllers served by a single Telco Central Office) using New Jersey tariffs as shown below:

Data Rate (KBPS)	No. of Controllers Per Channel	Monthly Cost Per Channel($)	Monthly Cost Per Channel($)
1.2	6 (voice grade)	76	12.67
9.6	28 (data channel)	499	17.82

Cost screening effectively eliminates leased digital channels from further consideration.

· **Step 9:** Complete the Technology Screening Process for Distribution Systems

Since the traffic system under design includes central computer control and NEMA TS1 controllers, it requires an RCU. Contacts with prospective suppliers indicated the availability of RCUs for either copper pair or fiber optic based technology.

· **Step 10:** Determine Potential Feasibility of a Backbone or Trunked System

Consider the case of a system implemented with wire lines. Without backbones or trunking, preliminary cable layouts require a total of 79,600 feet of cable, of which 76,000 feet is six (6) pair cable (assume a multiplex scheme using six (6) controllers). Trunking or backbones only reduce these runs to 78,000 feet. Since a backbone or trunking system offers no opportunity to reduce distribution system costs, eliminate link type CCFX.

· **Step 11:** Determine Whether a Change in Media Provides a Reasonable Candidate

The system geometry features a control center adjacent to a relatively compact group of controllers. There are no long haul data requirements or right of way obstructions. This eliminates the requirement for another medium in a line haul capacity. Eliminate link types CCMC and FNFC at this step.

· **Step 12:** Define Technology and Multiplexing Alternatives for the Distribution System

Based on column 9 of Figure 11-6, only consider link type CCFC. Candidate communication technologies include:

- Twisted wire pairs (owned)
- Leased voice grade channels
- Fiber optics

This step defines the best multiplexing alternative and approximate data rates. Use time division multiplexing with all alternatives.

- Twisted Wire Pairs

Figure 11-5 shows 14 controllers in a horizontal row. To provide this row with full duplex service, a non-multiplexed arrangement would typically use a 50 pair cable. Since an RCU appears necessary with or without multiplexing, the additional wire required makes the non-multiplexing option more expensive. Furthermore, the large amount of cable with large numbers of conductors (50 or more) unnecessarily reduces maintainability in the event of a severed cable.

Step 7 determined that six controllers could be serviced by a standard 1200 BPS channel. Step 10 indicated a six pair cable could accommodate this arrangement. Thus, the system does not need a higher data rate channel.

- Leased Voice Grade Channels

Using the same multiplex scheme as for twisted wire pairs, each channel can serve six controllers. Since the New Jersey tariff (Table 6-19) shows no additional monthly cost for full duplex service, use this more reliable service. Typically, the Telco Central Office bridges cables for six field controllers (with possibly an additional charge for bridging equipment) and routes the channel to the control center.

- Fiber Optic Lines

Using a data rate of 9600 BPS, the horizontal row of 14 controllers in Figure 11-5 can be multiplexed on one fiber optic channel. Fiber optic cables of six or fewer fibers can service the network.

Since all candidates represent distribution systems, combine Steps 13 and 14.

· **Steps 13 & 14:** Develop Cost Estimate for Candidates

Perform a preliminary cost analysis for each candidate identified in Step 12. Tables 11-7, 11-8 and 11-9 show the analysis which includes both capital and operating cost expressed as present worth. Rounded off results are:

Candidate	Present Worth ($)
Twisted Wire Pair	1,926,000
Leased Telephone Lines	2,118,000
Fiber Optics	2,277,000

· **Step 15:** Determine Remaining Non-Quantifiable Issues

The cost differential between the highest and lowest alternative approximates 18% of the lowest cost alternative. In this situation, give considerable weight to factors not easily quantified as described in Table 11-10. Because of non-quantifiable issues, the procedure sequences to Step 17.

· **Step 17:** Select Communication System Based on Cost and Other Factors

Comparison of the non-quantifiable issues for the land line alternatives indicates an advantage of fiber optics over TWP on two issues. Since the agency currently has good maintenance capability (Table 11-4), a fiber optics system should not pose any difficulty. Select the fiber optic alternative over TWP because better service quality and greater expansion capability outweigh the small cost differential.

Although a higher cost alternative, select the fiber optic alternative over Telco also because it proves better on four issues and worse on only one. Do not evaluate additional capacity because evaluation depends on the expansion particulars.

· **Step 18:** Review and Iterate if Necessary

The fiber optic design alternative appears technically acceptable, reliable, maintainable, and will provide a high quality of communication service. Since the capitalized cost appears modest for the service provided, do not iterate further.

Example 2 - Closed Loop System for Suburban Arterial

· **Step 1:** Describe Traffic System Architecture

Table 11-11 defines this as a closed loop system of forty controllers with field master Plan for dial up service to the control center.

· **Step 2:** Identify Candidate Communication Architectures

Closed loop systems use the distributed architecture shown in Figure 11-2B.

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit	50	Feet	15,600	780,000	0.05	39,000
Remote Communications Unit	1,200	Unit	196	235,200	0.1	23,520
Modems (C.O.)	180	Unit	33	5,940	0.1	594
Cable in Conduit 6 Pair 25 Pair 50 Pair	 1 1.5 2.5	 Feet Feet Feet	 76,000 1,600 2,000	 76,000 2,400 5,000	 0.05 0.05 0.05	 3,800 120 250
Remove old cable and clean conduit	3	Feet	62,400	187,200		
TOTAL				1,291,740		67,284

Table 11-7 Example 1, Cost Estimate TWP (Differential Between Alternatives)

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit	50	Feet	3,920	196,000	0.05	9,800
Remote Communications Unit	1,200	Unit	196	235,200	0.1	23,520
Modems (C.O.)	180	Unit	33	5,940	0.1	594
Cable in Conduit 6 Pair	1.8	Feet	3,920	7,056	0.05	353
Aerial Cable 6 Pair	3.3	Feet	3,920	12,936	0.05	647
TELCO Non-Recurring	143	Unit	196	28,028	0	
Total Construction				485,160		34,914
Annual TELCO Lease Charge	4,192	Circuit	33			138,336
Total Annual Charges						173,250

Table 11-8 Example 1, Cost Estimate TELCO (Differential Between Alternatives)

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit	50	Feet	15,600	780,000	0.05	39,000
Remote Communications Unit	1,500	Unit	196	294,000	0.1	29,400
Modems (C.O.)	415	Unit	33	13,695	0.1	1,370
Fiber in Conduit 6 Pair	3	Feet	78,000	234,000	0.05	11,700
Remove old cable and clean conduit	3	Feet	62,400	187,200	0	0
TOTAL				1,508,895		81,470

Table 11-9 Example 1, Cost Estimate Fiber (Differential Between Alternatives)

Non-Quantifiable Issue	Design Alternatives		
	Twisted Wire Pair	TELCO	Fiber Optic
1. Possible future escalation of lease costs beyond inflation	N/A	Negative factor	N/A
2. Exposure of operating agency to long term telecommunication charge commitment	N/A	Negative factor	N/A
3. Response to unforeseen need for additional communication capacity	Lower than fiber optics	Lowest with specified capability. High level of expansion possible at increased cost	N/A
4. Quality of service	Good	Satisfactory, but lower than owned lines	Best
5. Reliability	High (1)	Satisfactory, but lower than owned lines	High (1)
6. Ease of maintenance	Good (2)	Highest	Good (2)

Table 11-10 Non-Quantifiable Issues for Example 1 ***Notes(1)***

Location and Number of Controllers

System wil provide for control of forty controllers on a high type arterial state highway. Forty controllers divided into five sections. Controllers spaced at approximate intervals of 0.4 miles.

Traffic Control System Architecture

- Closed loop system.
- New NEMA TS-2 controllers

- Control center located 15 miles from most southern controller. Continuous communication between the field master and control center not required.

- No TV requirement.

Operating Agency Capability, Current Resources and Institutional Issues

- Currently maintains own signals, fair maintenance capability using simple technologies.

- No current interconnect on this facility.

- Poles available and within 100 feet of each controller, and at an average distance of 50 feet.

- No terrestrial microwave channels available below 31 GHz band.

- Franchise agreements include right to use Telco and power company poles.

- Significant expansion not expected.

- No area radio network frequencies available.

- Prefer conventional communication standards.

- Each closed loop section (master) will have its own communication channel for reliability resaons.

Communication Services Available

- Telco is only communication firm currently available in all parts of this area. Use New Jersey tariffs for comparison.

- CATV not currently available on this highway.

Table 11-11 Scenario for Example 2

- **Step 3:** Identify Generic Link Types

  Identify the link types in Figure 11-2B as:

Type	Definition
FMFC	Field Master to Field Controller
CCFM	Control Center to Field Master

- **Step 4:** Identify Candidate Technologies

  Develop columns 1 and 2 of Figure 11-10 from the technology/link type relationships of Table 11-3A.

- **Step 5:** Preliminary Technology Screening

  Since link CCFM does not require continuous service, owned land lines clearly cost more than switched services. Omit from further consideration on this link. Table 11-12 summarizes the reasons for termination of consideration.

1. Cost dominated by switched services.
2. No channels available.
3. Only 31 GHz and higher frequency channels available.
4. Distance to control center too long for 31 GHz channels.
5. Vendor base too narrow and technology too immature for this application.

Table 11-12 Reasons for Terminating Consideration of Candidates (Example 2)

· **Step 6:** Perform Screening for Institutional Issues

No channels are available for area radio networks. Only 31 GHz channels and above are available for terrestrial microwave. Eliminate this candidate for link type CCFM since equipment is incompatible with fifteen mile range.

· **Step 7:** Estimate Data Rate Requirements for Field Controllers and Screen Candidates

Closed loop systems using NEMA controllers generally provide for the coordination of 24 to 32 controllers from a field master using a single communication channel with a data rate of 1200 bps. All remaining candidate technologies can accommodate this rate.

· **Step 8:** Perform Cost Dominant Screening for Leased Communication Channels

Only one leased channel candidate (voice grade channel) appears in column 6 of Figure 11-10.

· **Step 9:** Complete the Technology Screening Process for Distribution Systems

Contact with closed loop traffic system vendors (at the time of handbook preparation) indicates:

- only one manufacturer would provide equipment using 31 GHz microwave technology, and
- one manufacturer would provide equipment using spread spectrum technology.

The operating agency finds this limitation unacceptable. Furthermore, the agency feels that limited operational experience with these technologies does not warrant further design investigations.

To support the consideration of utility poles for the owned cable candidates, perform a survey to determine whether the poles can accept these lines. The survey proves affirmative; however, in a number of cases utility adjustments are required.

· **Step 10:** Determine Potential Feasibility of Backbone or Trunking

This communications architecture contains no backbone or trunking links.

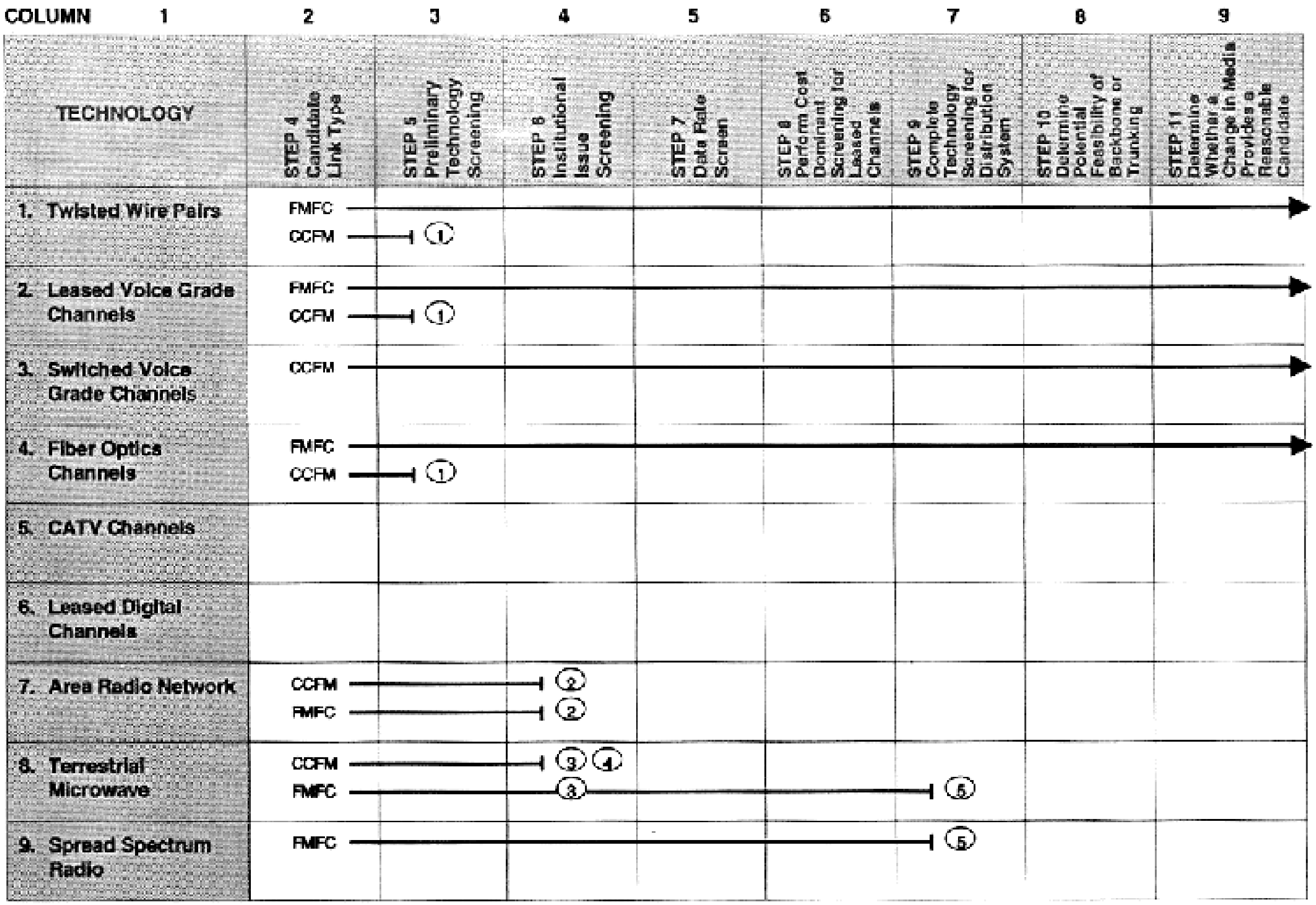

Figure 11-10 Communication Candidate Analysis Summary Chart for Example 2

- **Step 11:** Determine Whether a Change in Media Provides Reasonable Candidate

Switched voice grade channels provide the line haul function. No geometric constraints require a media change in the distribution system.

- **Step 12:** Define Technology and Multiplexing Alternatives for the Distribution System

The closed loop system architecture will use dial up telephone service between the control center and the field master. Locate a field master at one local controller site in each section.

From column 9 of Figure 11-10, link type FMFC remains the only distribution system link type to consider. Candidate communication technologies include:

- Twisted wire pairs (owned)
- Leased voice grade channels
- Fiber optics

In each case the traffic system manufacturer's equipment will communicate over a single channel to the eight controllers in each section. Most manufacturers use time division multiplexing for this purpose at a data rate of 1200 bps.

The TWP alternative will connect the field master with each field controller via overhead cable runs of six (6) pair cable on utility poles. Underground conduit will connect the pole location to the controllers. The fiber optics alternative follows the same routing using a four fiber cable (two cables for communication and two spares).

A single central office serves the Telco drops for each section. Underground conduit runs connect poles to the controllers.

· **Steps 13 & 14:** Develop Cost Estimate for Candidates

Perform a preliminary cost analysis for each candidate identified in Step 12. Tables 11-13, 11-14 and 11-15 show the analysis which includes both capital and operating cost expressed as present worth. Rounded off results follow:

Candidate	Present Worth
1. Twisted wire pair	$571,000
2. Leased telephone lines	330,000
3. Fiber optics	828,000

· **Step 15:** Determine Whether There Are Remaining Non-Quantifiable Issues

While the issues generally appear similar to Table 11-10, their importance for this example differs somewhat from Example 1. In this case, the agency has a less sophisticated maintenance capability. In addition, the distribution system for the owned cable consists largely of aerial cable with its greater exposure to damage from lightning and weather. Step 17 provides the final evaluation.

· **Step 17:** Select Communication System Based on Cost and Other Factors

Comparing the land line alternatives, the fiber optic system costs approximately 45% more than TWP. As the agency appears less prepared to maintain fiber optics technology, cost and maintenance factors outweigh the advantages of fiber optics.

With the current estimated cost of TWP approximately 73% greater than leased lines, and with Telco providing responsive maintenance in the event of line damage, Telco appears the more attractive alternative. The agency's capital investment can shift to an owned land line alternative, if future leasing costs become unacceptable.

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit	50	Feet	2,000	100,000	0.05	5,000
Modems (Master)	200	Unit	5	1,000	0.1	100
Cable in Conduit 6 Pair	1	Feet	2,000	2,000	0.05	100
Aerial TWP Cable	3.3	Feet	73,920	243,936	0.05	12,197
Pole Adaption	1,500	Unit	40	60,000	0	0
TOTAL				406,936		17,397

PRESENT WORTH FACTOR (7%, 15 YR) 9.4231 PRESNT WORTH $570,868

Table 11-13 Example 2, Cost Estimate TWP (Differential Between Alternatives)

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit	50	Feet	2,000	100,000	0.05	5,000
Modem (Master)	200	Unit	5	1,000	0.1	100
Cable in Conduit 6 Pair	1	Feet	2,000	2,000	0.05	100
TELCO Non-Recurring	143	Unit	40	5,720	0	0
Total Construction				108,720		5,200
Annual TELCO Lease Charge	3,648	Circuit	5			18,240
Total Annual Charges						23,440

PRESENT WORTH FACTOR (7%, 15 YR) 9.4231 PRESENT WORTH $329,597

Table 11-14 Example 2, Cost Estimate TELCO (Differential Between Alternatives)

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit	50	Feet	2,000	100,000	0.05	5,000
Fiber Modem	415	Unit	40	16,600	0.1	1,660
Modem (Master)	415	Unit	5	2,075	0.1	207.5
Fiber in Conduit 6 Pair	3	Feet	2,000	6,000	0.05	300
Aerial Fiber Cable	5.3	Feet	73,920	391,776	0.05	19,589
Pole Adaption	1,500	Unit	40	60,000	0	0
TOTAL				576,451		26,756

PRESENT WORTH FACTOR (7%, 15 YR) 9.4231 **PRESENT WORTH $828,578**

Table 11-15 Example 2, Cost Estimate Fiber (Differential Between Alternatives)

- **Step 18:** Review and Iterate if Necessary

  The Telco alternative is technically acceptable, reliable and maintainable at a modest capitalized cost; thus do not iterate further. Since the NEMA TS2 specification already includes a suitable modem, no additional field communication equipment is required. Therefore, specify NEMA TS2 type controller.

Example 3 - Freeway Surveillance and Control System

The following paragraphs describe the steps in analyzing the data communication requirements.

- **Step 1:** Describe Traffic System Architecture

  Table 11-16 describes the central traffic control concept. TV monitors are located in the traffic operations center, as well as a separate CMS central controller. Operators select messages manually based on loop surveillance and CCTV information. Figure 11-11 shows the field equipment layout.

- **Step 2:** Identify Candidate Communication Architectures

  Candidate communications architectures shown in Figure 11-2 include Figures 11-2A (without land lines as no right of way exists to the control center), 11-2C, 11-2D and 11-2F.

- **Step 3:** Identify Generic Link Types

  Identify the link types associated with the remaining candidate communication architectures identified in Step 2 as:

CCFC	Control Center to Field Controller
FNFC	Field Node to Field Controller
CCFX	Control Center to Field Multiplexer
CCMC	Control Center to Media Converter
CHCH	Communication Hub to Communication Hub

· **Step 4:** Identify Candidate Technologies

Because this example contains a requirement for video communication, use two candidate analysis summary charts (Figures 11-12 and 11-13). Develop columns 1 and 2 for each figure from the technology/link type relationships of Tables 11-3A and 11-3B. Add packet radio service to Table 11-3A as a technology candidate.

· **Step 5:** Perform Preliminary Technology Screening

Eliminate link candidates requiring right of way, CATV, microwave and spread spectrum radio back to the control center. Tables 11-17 and 11-18 list relevant notes.

· **Step 6:** Perform Screening for Institutional Issues

Eliminate area radio networks. Eliminate spread spectrum radio for video requirement.

1. No right-of-way to control center.
2. CATV not close to highway.
3. Distance to control center exceeds range limitations of 31 GHz microwave.
4. Distance to control center exceeds range limitations of spread spectrum radio.
5. State DOT prefers to retain use of ARN channels for services currently using these channels.
6. Voice grade channel costs lower.
7. Digital channel costs lower.
8. Probable line of sight problems.
9. Not compatible with range of 31 GHz microwave.

Table 11-17 Reasons for Terminating Consideration of Candidates (Example 3 - Data)

Location and Types of Equipment

The system will provide surveillance and control for a section of freeway in a highly populated suburban area. This freeway is one of several controlled from a traffic operations center located 10 miles from the western end of the freeway. No right-of-way exists between the operations center and the freeway. Meter nine interchanges in each direction. Provide three TV cameras and three changeable message signs.

Traffic Control System Architecture

- Central type architecture.
- Each Type 170 ramp meter controls the ramp, and processes ramp and adjacent mainline detector data. A seperate Type 170 processes the data for each detector station. The system contains a total of 60 Type 170 controllers. Polling period length is 20 seconds.
- A field controller with a serial port drives the changeable message signs. A data rate of 1200 bps supports each CMS.
- Average run of 420 feet to a power and Telco tie point sharing the same pole.

Operating Agency Capability, Current Resources and Institutional Issues

- State maintains own signals; good maintenance capability with prior experience with surveillance systems.
- No current conduit or interconnect on this facility.
- No terrestrial microwave channels available below 31 GHz band.
- No additional area radio network frequencies are available. The State DOT does, however, have the option of redirecting the use of several existing channels.
- A single point of failure in the communication system should cause a loss of communication with no more than 20% of the ramp metering of surveillance system controllers.
- This represents the first of several such similar new installations in the area. The State DOT wants to identify an appropriate cost effective communications design which they may use on similar facilities.
- Additional video cameras may be added in the future.

Communication Services Available

- Telco provides service. Use New Jersey tariffs for comparison.
- Packet radio service at 4.8 KBPS available.
- CATV access not close to highway.

Table 11-16 Scenario for Example 3

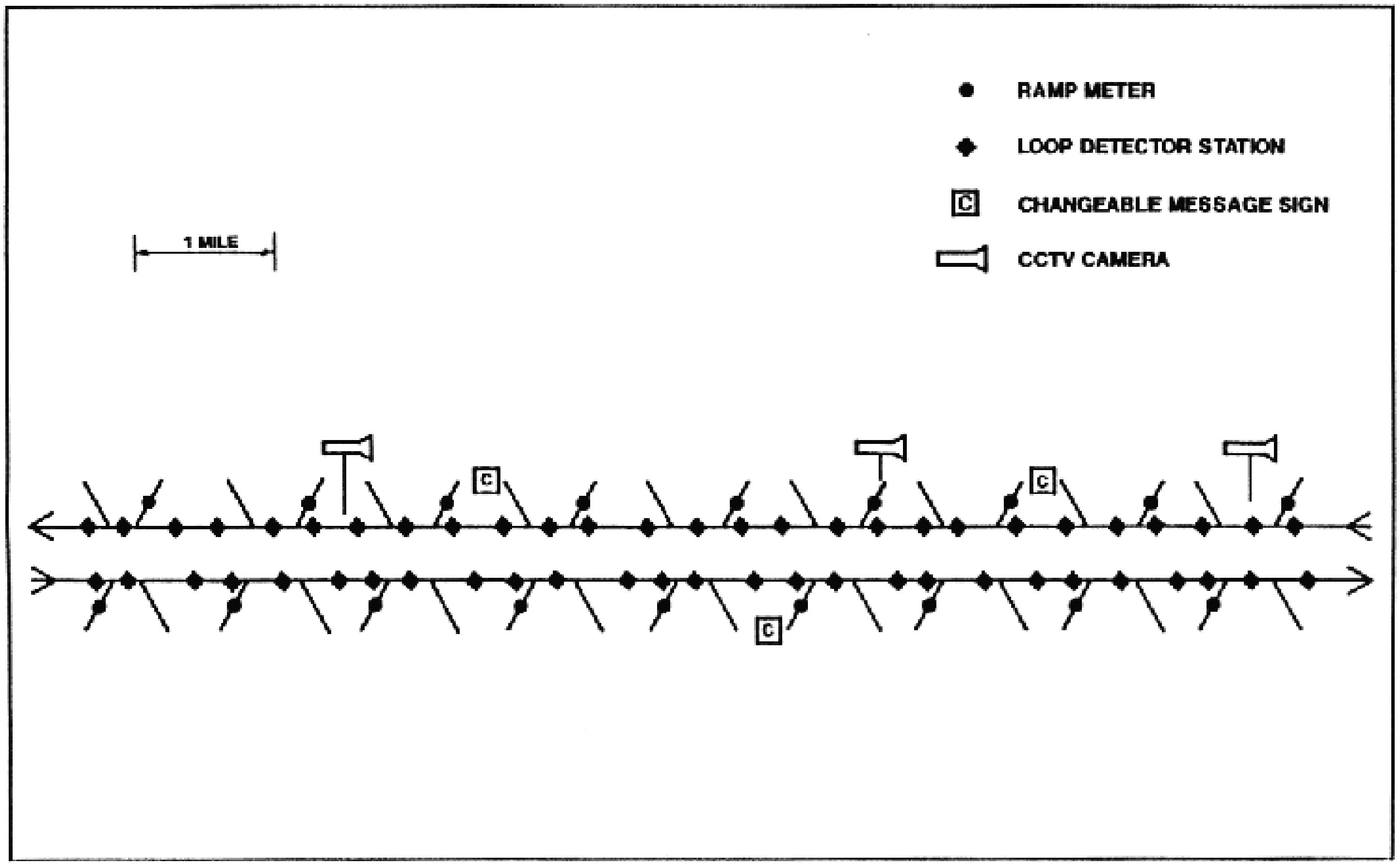

Figure 11-11 Equipment Layout for Example 3

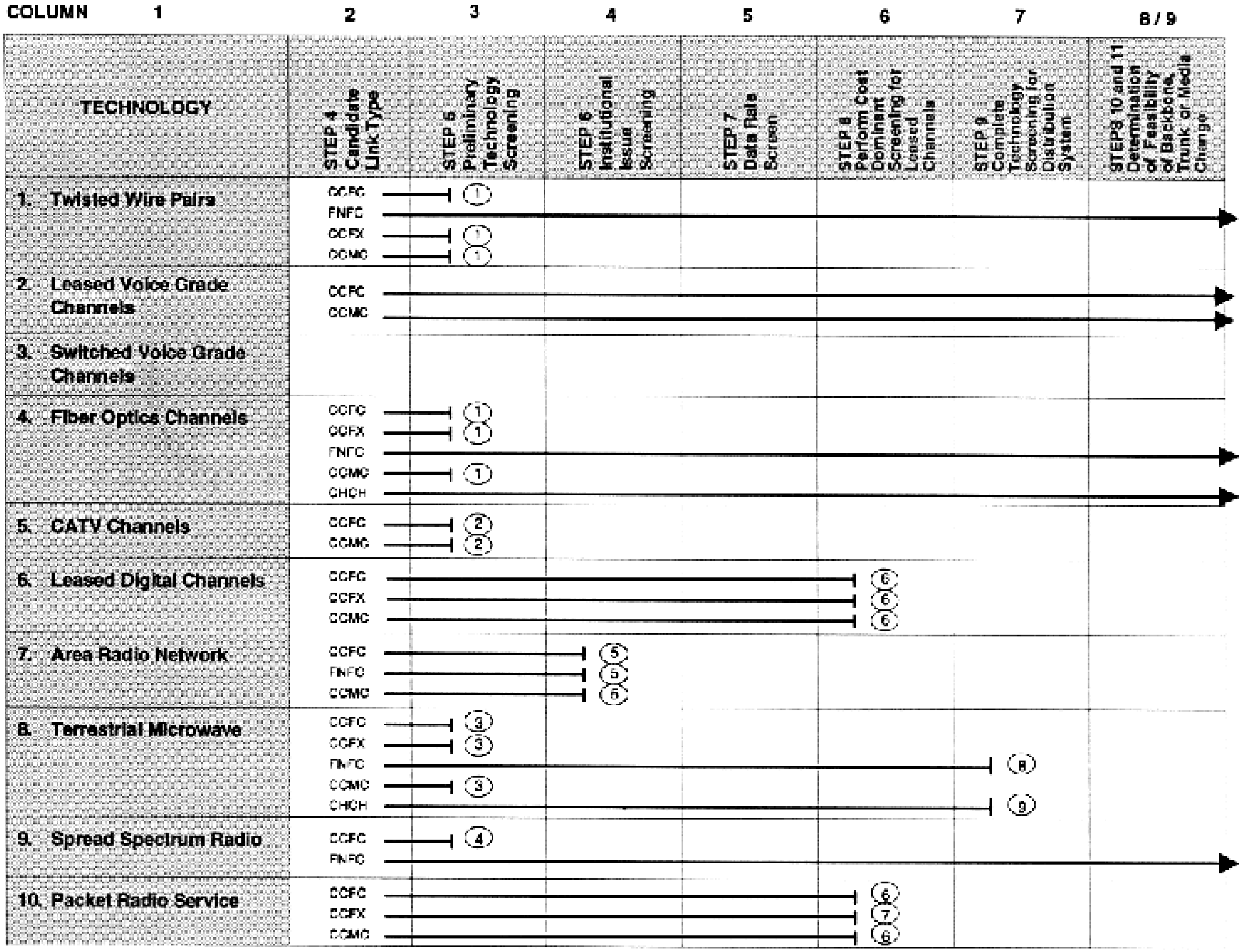

Figure 11-12 Communication Candidate Analysis Summary Chart for Data Communication Requirements for Example 3

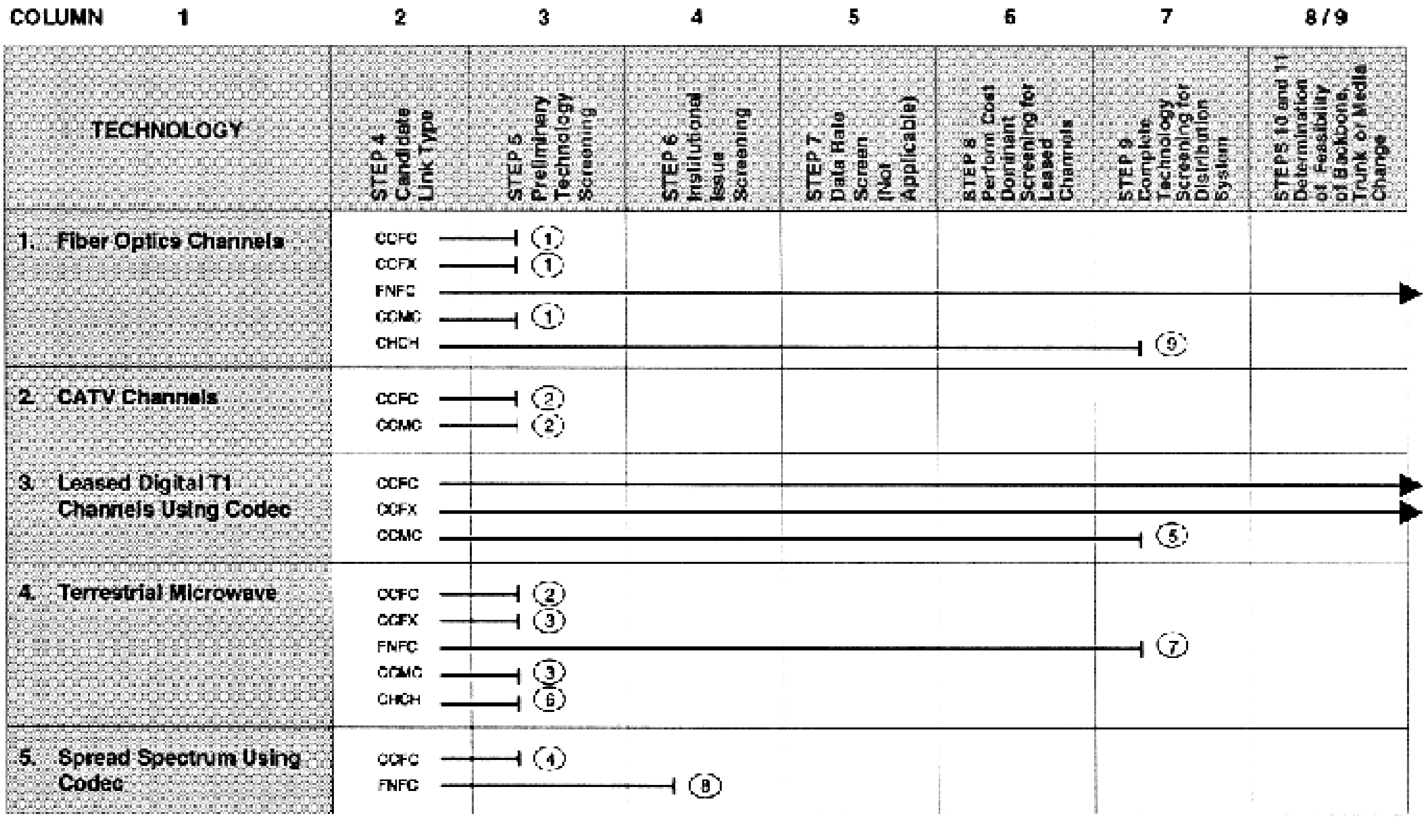

Figure 11-13 Communication Candidate Analysis Summary Chart for Video Commuciation Requirements for Example 3

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit	50	Feet	2,000	100,000	0.05	5,000
Modem (Master)	200	Unit	5	1,000	0.1	100
Cable in Conduit 6 Pair	1	Feet	2,000	2,000	0.05	100
TELCO Non-Recurring	143	Unit	40	5,720	0	0
Total Construction				108,720		5,200
Annual TELCO Lease Charge	3,648	Circuit	5			18,240
Total Annual Charges						23,440

PRESENT WORTH FACTOR (7%, 15 YR) 9.4231 PRESENT WORTH $329,597
Table 11-14 Example 2, Cost Estimate TELCO (Differential Between Alternatives)

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit	50	Feet	2,000	100,000	0.05	5,000
Fiber Modem	415	Unit	40	16,600	0.1	1,660
Modem (Master)	415	Unit	5	2,075	0.1	207.5
Fiber in Conduit 6 Pair	3	Feet	2,000	6,000	0.05	300
Aerial Fiber Cable	5.3	Feet	73,920	391,776	0.05	19,589
Pole Adaption	1,500	Unit	40	60,000	0	0
TOTAL				576,451		26,756

PRESENT WORTH FACTOR (7%, 15 TR) 9.4231 PRESENT WORTH $828,578
Table 11-15 Example 2, Cost Estimate Fiber (Differential Between Alternatives)

1. No right-of-way to control center.
2. CATV not near highway.
3. Range to control center too long for 31 GHz microwave.
4. Distance to contorl center esceeds range limitations of spread spectrum radio.
5. If video signals were returned to a single point on the highway for leased digital transmission to the control center, multiplexing (link type CCFX) would be used for transmission to the control center.
6. Range and line of sight limitations with 31 GHz microwave.
7. Probable line of sight problems.
8. Coded viedo multiplexing with data too great a technical risk at this time.
9. Too few video channels for multiplexing effectiveness.

Table 11-18 Reasons for Terminating Consideration of Candidates (Example 3 - Video)

· **Step 7:** Estimate Data Rate Requirements for Field Controllers and Screen Candidates

Because the field data transmission requirements for the controllers in this example resemble the example in Chapter 4, page 4-13, the procedures identified in Table 4-6 and in spreadsheet file SURVLON2.WK1 described in Appendix B apply here. Since reliability considerations do not permit more than 20% or 12 controllers on a channel, the spreadsheet was run for this number of controllers at a 1200 BPS data rate and is shown in Figure 11-14. The twelve controllers require approximately 53% of the channel capacity. Five channels are required.

Because CMS often use the manufacturer's computer and software at the traffic operations center, for CMS operation, it is often more convenient to provide channels reserved for those devices. Since the multiplexing capabilities of the protocols vary from manufacturer to manufacturer, and since most manufacturers can use 1200 BPS channels, the final design will most likely use from one to three of those channels for CMS control.

Figure 11-14 shows that this system design requires approximately 74 functional bytes per controller (without overhead) based on a channel servicing 12 controllers. When adding provisions for design growth and overhead, each controller requires a data rate of approximately 50 BPS. Twelve controllers will require approximately 53% of the capacity of a 1200 BPS channel. Based on this, the 54 Type 170 controllers require five such channels and the CMS require three such channels.

Do not eliminate communication candidates as a result of these requirements.

· **Step 8:** Perform Cost Dominant Screening for Leased Communication Channels

The following paragraphs develop the cost analysis for leased channels to field controllers and CMS.

Telco leased voice grade channels cost less than the per controller cost of leased digital channels for data transmission as described in Step 8 of Example 1. Therefore, eliminate digital channels for data transmission. The following paragraphs discuss Telco comparisons with the packet radio service candidate for data transmission.

FREEWAY SURVEILLANCE - LONG PROCESSING PERIOD
PRELIMINARY ASSESSMENT OF DESIGN

			VALUE ENTRY		
1	POLLING PERIOD T (SEC)		20		
2	MAXIMUM # DETECTORS PER CONTROLLER - D		25		
3	MAXIMUM # SPEED TRAPS PER CONTROLLER - S		10		
4	MAXIMUM # CONTROLLERS ON CHANNEL - C		12		
5	CHANNEL SETTLING TIME (SEC.) - H		0.03		
	FLOW AND ERROR CONTROL				
6	OVERHEAD RATIO (%) - R		40		
7	DESIGN GROWTH FACTOR (%) - G		20		
8	CHANNEL DATA RATE (BITS/SEC)		1200		
9	COMPUTATION OF BYTES PER CONTROLLER	RELATIONSHIP		BYTES PER CONTROLLER	
10	OUTBOUND MESSAGE				
11	CONTROLLER ADDRESS	INT(1.4438LN(C) + 0.99)/8		0.5	
12	TIME OR SYNCHRONIZATION REFERENCE	0 - 5 BYTES, VARIES WITH DESIGN		5.000	
13	MODES AND PLAN SELECTION			0.750	
14	RESET DETECTORS			0.125	
15	SPECIAL FUNCTIONS AND SPARES			2.000	
16	DOWNLOAD	6 INFO + 6 ID BYTES/POLL		12.000	
17	INBOUND MESSAGE				
18	METERING MODE IDENTIFICATION			0.250	
19	PROCESSOR FAILURE/BULB FAILURE			0.250	
20	METERING RATE IMPLEMENTED BY CONTROLLER			0.500	
21	OUTBOUND COMMUNICATION ERROR PRESENCE			0.125	
22	SPARES			2.000	
23	UPLOAD	6 INFO BYTES/POLL		6.000	
24	REQUIREMENTS PER DETECTOR AND TRAP				
25	OCCUPANCY AND DETECTOR FAILURE STATUS			0.875	
26	MAXIMUM COUNT (FOR VOLUME)	INT(1.443*LN(.8*T)+0.99)/8		0.500	
27	SPEED TRAP AND FAILURE STATUS			0.875	
28	TOTAL DETECTOR BYTES PER CONTROLLER	D*(LINE 25+LINE 26) S*(LINE 27)		43.125	
29	TOTAL FUNCTIONAL BYTES/POLL/CONTROLLER	INT(SUM(LINE 11-16)+.99) + INT(SUM(LINE 17-23)+LINE28+.99)			74.000
				BYTES & BITS PER CHANNEL	
30	TOTAL FUNCTIONAL BYTES/POLL/CHANNEL	(LINE 4)*(LINE 29)		888.000	
31	TOTAL FUNCTIONAL BITS/POLL/CHANNEL	8*(LINE 30)		7104.000	
32	TOTAL BITS PER POLL WITH OVERHEAD	INT((LINE 34)*(1+R/100)+.99)			9945.600
33	TOTAL BITS/POLL WITH DESIGN GROWTH & OH	INT((LINE 35)*(1+G/100)+.99)			11934.720
34	BPS PER CONTROLLER WITH GROWTH & OH	(LINE 33)/C		49.728	
35	FRACTION OF CHANNEL USED	(LINE 34)/B + 2*C*H		0.533	

Figure 11-14 Evaluation of 12 Controllers on 1200 BPS Channel

Telco Leased Voice Grade Channels

Factors for cost estimation:

- Type 170 channels have twelve (12) terminations
- CMS channels have two terminations
- 60% of field equipment in the area served by Telco Central Office A
- 40% of field equipment in the area served by Telco Central Office B
- The traffic management center served by Telco Central Office C 10 miles from Offices A and B

Estimate the monthly cost per Type 170 channel as follows:

Thirteen channel terminations	
12 at $38	$456
Bridging in Telco Central Office	
$50	50
Interoffice fixed charge	15
Interoffice mileage charge	
$0.50 at 10	5
Total $526	

Estimate the monthly cost per CMS channel:

Two channel terminations	
2 at $ 38	$76
Interoffice fixed charge	15
Interoffice mileage charge	
$0.05 at 10	5
Total $96	

Total cost

5 Type 170 controller channels	
5 at $ 526	$2,630
3 CMS channels	
3 at $ 96	288
Total Monthly Charge	$2,918

Packet Radio Service

Estimate the packet charges as follows:

$ .03 per message initiation
$ .04 per 100 bytes

Step 7 shows less than 100 bytes required for a Type 170 controller message in each direction. Estimate the cost for a single polling cycle for each controller as:

2 x (.03 + .04) = $ .14

At a polling period of 20 seconds (3 times per minute), the monthly service cost for a single controller approximates:

3 x 60 x 24 x 30 x .14 = $18,000

As this costs many times the Telco charge, eliminate the packet service approach as a candidate for field link communication (link type CCFC). This high rate will also eliminate packet service for the CCFX and CCMC type channels.

· **Step 9:** Complete the Technology Screening Process for Distribution Systems

Consider the possible application of terrestrial microwave to the CHCH and FNFC links. Channel availability considerations limit use to 31 GHz and above for this scenario. For a backbone system, hub spacing will likely exceed the range of 31 GHz microwave at this frequency. Therefore, eliminate use of microwave for the CHCH link. To use terrestrial microwave for the FNFC link (a distribution system type of link), the system will likely require a "daisy chain" arrangement. Highway topology indicates line of sight interruptions will likely occur, thus requiring repeaters (and associated power). As detailed engineering studies would be needed to establish the technical feasibility of this alternative, do not pursue it further at this time.

· **Steps 10 and 11:** Determine the Potential Feasibility of a Backbone or Trunked System and Media Change

Identify candidate systems from Figures 11-12 and 11-13. Define the data and video candidates to complement each other (i.e. both applications should generally maximize the same conduit/trench or should avoid using land lines).

Since no right-of-way to the traffic management center exists, identify a trunk or media change link to use the distribution systems on available rights-of-way.

Table 11-19 describes the types of candidate systems to be considered further.

· **Step 12:** Define Technology and Multiplexing Alternatives

Table 11-19 describes the technologies and multiplexing alternatives for Candidates 1 and 3 and three alternatives for Candidate 2. Each alternative uses leased T1 communications to a tie point with single mode fiber communications to codec equipped cameras. Five voice grade channels tie the control center to the freeway. Alternatives for the distribution of data on the freeway follow:

A. Each controller served by one of five fiber optic channels.
B. Each controller served by one of five WP channels.
C. Use of a redundant fiber backbone with fiber or TWP from backbone hubs to controllers.

Eliminate Alternative B in favor of Alternative A because, for buried conduit systems, cost differentials between these technologies prove small and the performance advantages of fiber outweigh them.

Alternative C provides a design with powerful future potential. In reality, the system's data requirements are modest and do not warrant the additional cost and complexity.

For comparative evaluation, further define Alternative A. Select as Candidate 2 the addition of spare fibers accessible on the freeway to both video and data channels.

· **Steps 13 and 14:** Develop Cost Estimates For Candidates

Perform a preliminary cost analysis for each candidate identified in Step 12. Tables 11-20, 11-21 and 11-22 show the analysis with capital and operating cost expressed as present worth. Rounded off results are:

Candidate	Present Worth
1. Telco direct to field devices	$ 1,802,000
2. Telco to fiber optics lines	1,851,000
3. Telco and spread spectrum radio	2,169,000

· **Step 15:** Determine Remaining Non- Quantifiable Issues

Table 11-23 identifies and evaluates the non-quantifiable issues. Step 17 performs the final evaluation.

· **Step 17:** Select Communication System Based on Cost and Other Factors

In this case, eliminate Candidate 3 since it:

- costs the most,

- rates poorly with respect to non-quantifiable factors.

With very little cost advantage to the wholly leased alternative, the advantages of the leased/owned fiber system with respect to possible expansion and lease cost escalation led the agency to select this alternative.

· **Step 18:** Review and Iterate if Necessary

The system selected should provide good performance with little risk and at an acceptable cost. Use of codec video, fiber optic lines and T1 multiplexing of the codec video signals provides a cost effective approach. No further iteration is required. During detailed design consider:

- multiplexing the data channels onto the T1 channel, and
- refining the fiber optic system.

Candidate Systems	Data Line Type	Video Link Type
1. Leased voice grade lines run directly to controllers. Leased T1 or fractional T1 lines using digitally coded video run to camera sites. Leased voice grade channels for data. ● 3 T1 or fractional T1 channels ● Eight (8) voice grade channels using TDM 1200 BPS channels	CCFC	CCFC
2. Leased communications to a tie point on the freeway, owned fiber on the freeway for data and video. ● Signals from video cameras are returned (via separate fiber channels) to the tie point. Codecs provide a 384 KBS signal for each of the three cameras. Multiplex these signals on a T1 channel and return to the control center. ● Data from control center to the tie points using TDM at 1200 BPS on five leased voice grade channels. Data transmission to controller and CMS on five TWP or fiber optic data channels. ● An alternative for data distribution system is to run the Telco data to one field point, use a single mode redundant fiber backbone and a multimode fiber or TWP distribution system to local controllers.	CCMC FNFC CHCH FNFC	CCFX FNFC
3. Leased communications to cameras, leased voice grade lines from control center to tie points or freeway and spread spectrum radio for data. ● Use T1 lines for video as for Candidate 1. ● Data from control center to five different tie points on freeway using five voice grade leased channels using TDM at 1200 BPS. Five spread spectrum radio channels used to distribute these signals to the field devices.	CCMC FNFC	CCFC

Table 11-19 Final Candidate Systems for Example 3

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit and Cable Codec to Telco	20	Feet	900	18,000	0.05	900
Conduit and Cable Shared Power Trench	6	Feet	11,200	67,200	0.05	3,360
Conduit and Cable Non-Shared Power Trench	20	Feet	11,600	232,000	0.05	11,600
Codec	13,000	Unit	6	78,000	0.1	7,800
T1 Terminal Equipment	10,000	Unit	6	60,000	0.1	6,000
TELCO Non-Recurring Voice Grade	9,295	Unit	1	9,295	0	0
TELCO Non-Recurring T1 Lines	8,220	Unit	1	8,220	0	0

Table 11-20 Example 3, Cost Estimate TELCO Direct to Field Devices (Differential Between Alternatives), Candidate 1 - #1

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Modems for 170 Controller	180	Unit	60	10,800	0.1	1,080
Modems for CMS	180	Unit	3	540	0.1	54
Modems (C.O.)	180	Unit	8	1,440	0.1	144
Total Construction				485,495		30,938
Annual Lease Charge-Voice						35,016
Annual Lease Charge-T1						73,800
Total Annual Charges						139,754

PRESENT WORTH FACTOR (7%, 15 YR) 9.4231 PRESENT WORTH $1,802,411

Table 11-20 Example 3, Cost Estimate TELCO Direct to Field Devices (Differential Between Alternatives), Candidate 1 - #2

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Modems for Telco Lines	180	Unit	10	1,800	0.1	180
Conduit and Cable Shared Power Trench	9	Feet	19,736	177,624	0.05	8,881
Conduit and Cable Non-Shared Power Trench	23	Feet	29,028	667,644	0.05	33,382
Codec	13,000	Unit	6	76,000	0.1	7,600
T1 Terminal Equipment	10,000	Unit	2	20,000	0.1	2,000
TELCO Non-Recurring Voice Grade	1,430	Unit	1	1,430	0	0
TELCO Non-Recurring T1 Lines	2,740	Unit	1	2,740	0	0

Table 11-21 Example 3, Cost Estimate TELCO and Fiber Optic Lines (Differential Between Alternatives), Candidate 2 - #1

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Modems for 170 Controller	400	Unit	60	24,000	0.1	2,400
Modems for CMS	400	Unit	3	1,200	0.1	120
F O Modems at Telco Point	400	Unit	5	2,000	0.1	200
Total Construction				974,038		54,723
Annual Lease Charge-Voice						13,248
Annual Lease Charge-T1						24,600
Total Annual Charges						92,811

PRESENT WORTH FACTOR (7%, 15 YR) 9.4231 PRESENT WORTH $1,851,009

Table 11-21 Example 3, Cost Estimate TELCO and Fiber Optic Lines (Differential Between Alternatives), Candidate 2 - #2

Item	Unit Cost Installed ($)	Quantity Dimensions	Quantity	Extension ($)	Annual Maintenance Factor	Annual Maintenance Factor ($)
Conduit and Cable Codec to Telco	20	Feet	900	18,000	0.05	900
Codec	13,000	Unit	6	78,000	0.1	7,800
T1 Terminal Equipment	10,000	Unit	6	60,000	0.1	6,000
TELCO Non-Recurring Voice Grade	9,295	Unit	1	1,430	0	0
TELCO Non-Recurring T-1 Lines	8,220	Unit	1	8,220	0	0
Spread Spectrum Radios	8,000	Unit	67	536,000	0.1	53,600
Voice Grade Modems	180	Unit	10	1,800	0.1	180
Total Construction				703,450		68,480
Annual Lease Charge-Voice						13,248
Annual Lease Charge-T1						73,800
Total Annual Charges						155,528

PRESENT WORTH FACTOR (7%, 15 YR) 9.4231 PRESENT WORTH $2,169,006

Table 11-22 Example 3, Cost Estimate TELCO and Spread Spectrum Radio (Differential Between Alternatives), Candidate 2

Non-Quantifiable Issues	Totally Leased Channels	Leased Channels with Fiber Optic Distribution	Leased Channels; Spread Spectrum Distribution for Data
1. Possible future escalation of lease costs beyond inflation	Highest risk	Less sensitive	High risk
2. Exposure of operating agency to future TELCO communication charges	Highest	Lower	High
3. Expansion capability	Lease cost increase proportional to expansion	Good data expansion Lease video cost increase at a fraction of expansion	Some data expansion possible Video lease cost increase proportional to expansion
4. Quality of Service	Good	Good	Data service quality ok, but lower
5. Reliability	High	High	Data reliability ok, but lower
6. Ease of Maintenance	Best	Good	Good

Table 11-23 Non-Qualifiable Issues for Example 3

Endnotes

1 (Popup)
1. Some simple fiber optic distribution system configurations may be daisy chained (failure of one unit may result in loss of communication with others). The line failure rate for TWP is, however, usually higher than for fiber optic.

2. Technology requirements for fiber optic maintenance may be higher than for TWP; however the anticipated frequency for TWP maintenance is higher.